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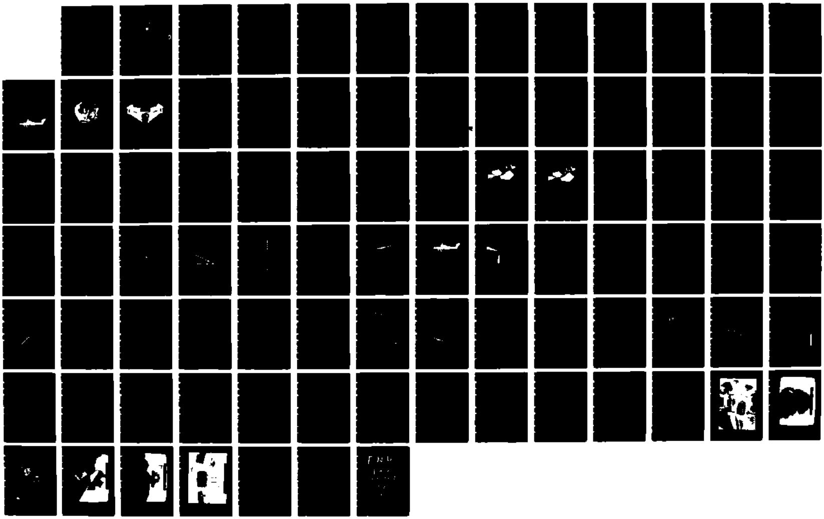

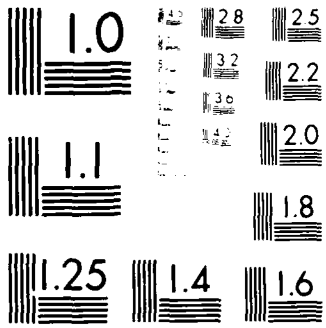

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

EXPERIMENTAL DESIGN
OF A PILOTED HELICOPTER
OFF-AXIS-TRACKING SIMULATION
USING A HELMET MOUNTED DISPLAY

by

Gerald J. Hopkins

September 1987

Thesis Advisor: Satya Bodapati

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The development of target tracking weaponry on the Army's Advanced Attack Helicopter (AAH) allows directional tracking with FLIR imagery at large angles from the longitudinal axis. A flight simulation using a helmet mounted display was conducted to quantify head tracking performance and to identify off-axis tracking limits for the aircraft's Pilot Night Vision Sensor. The experimental parameters included varying flight trajectories (hover, rectilinear, and curvilinear paths) and the target velocities and ranges. This paper details the design efforts in creating tracking scenarios in the simulator and the head tracking algorithms used to generate command profiles for perfect line of sight tracking performance. Confidence in the algorithms for tracking data calculations was

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Experimental Design of a Piloted Helicopter Off-Axis-Tracking Simulation Using a Helmet Mounted Display

by

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Captain, United States Army
B.S., United States Military Academy, 1980

Submitted in partial fulfilment of the requirements for the degree of

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ABSTRACT

The development of target tracking weaponry on the Army's Advanced Attack Helicopter (AAH) allows directional tracking with FLIR imagery at large angles from the longitudinal axis. A flight simulation using a helmet mounted display was conducted to quantify head tracking performance and to identify off-axis tracking limits for the aircraft's Pilot Night Vision Sensor. The experimental parameters included varying flight trajectories (hover, rectilinear, and curvilinear paths) and the target velocities and ranges. This paper details the design efforts in creating tracking scenarios in the simulator and the head tracking algorithms used to generate command profiles for perfect line of sight tracking performance. Confidence in the algorithms for tracking data calculations was essential to experimental conclusions on human tracking behavior and performance. The successful attempt to replicate the night vision system of the AAH is also discussed.

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TABLE OF ABBREVIATIONS

AZT	Azimuth angle to Target (deg.)
CG	Center of Gravity
CGI	Computer Generated Imagery
CPG	Copilot/Gunner
ELT	Elevation angle to Target (deg.)
FLIR	Forward Looking Infrared
FOV	Field of View
FOR	Field of Regard
HDU	Helmet Display Unit
HMD	Helmet Mounted Display
HUD	Heads Up Display
ICAB	Interchangeable Cab
IHADSS	Integrated Helmet and Display Sight System
LHX	Light Helicopter Experimental
NED	North, East, Down (conventional RH axis system)
NEU	North, East, Up (simulation LH axis system)
NOE	Nap-of-the-Earth
PNVS	Pilot Night Vision Sensor
SEU	Sight Electronics Unit
SSU	Sensor Survey Unit
TADS	Target Acquisition Designation Sight
VMS	Vertical Motion Simulator

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I. INTRODUCTION

The combat success of the attack helicopter on future battlefields will rely heavily upon the pilot and gunner's precise capability to see and engage threat targets. The inherent ability to fly missions in adverse weather, nap-of-the-earth (NOE) and at night must be provided through aircraft subsystems that visually assist the crew to navigate and to acquire and track targets accurately. Numerous configurations such as Head Up Displays (HUD), Helmet Mounted Sights/Displays (HMS/D), Forward Looking Infrared (FLIR) and Night Vision Goggles (NVG) are currently employed in various aircraft to meet this need. Important to the justification of training, operational use, continued production, and improvement of such systems is the need for quantifiable measures of pilot performance . In addition, performance data ought to be utilized in defining operational limits for these systems.

In the U.S. Army's AH-64 Advanced Attack Helicopter (Apache), two independent sensor systems optically aid the pilot and co-pilot/gunner (CPG). The Pilot Night Vision Sensor (PNVS) represents a significant effort to give the pilot the ability to fly at night and navigate. A nose mounted FLIR camera in a rotating turret sends thermal imagery to a HMD monocle in front of the right eye along with flight symbology from a symbol generator. Pilot line of sight simultaneously drives the camera viewing direction and a turreted 30mm chain gun below the cockpit. In addition, the Target Acquisition Designation Sight (TADS) below the PNVS, provides the CPG with day and night target acquisition and tracking capability through an optical telescope, day television and a second FLIR. Similar arrangements drive the TADS FLIR and the chain gun. Wide field of view TADS is available to the pilot in case of PNVS failure whereas PNVS is overridden to the CPG only in the event of pilot incapacitation. [Ref. 1]

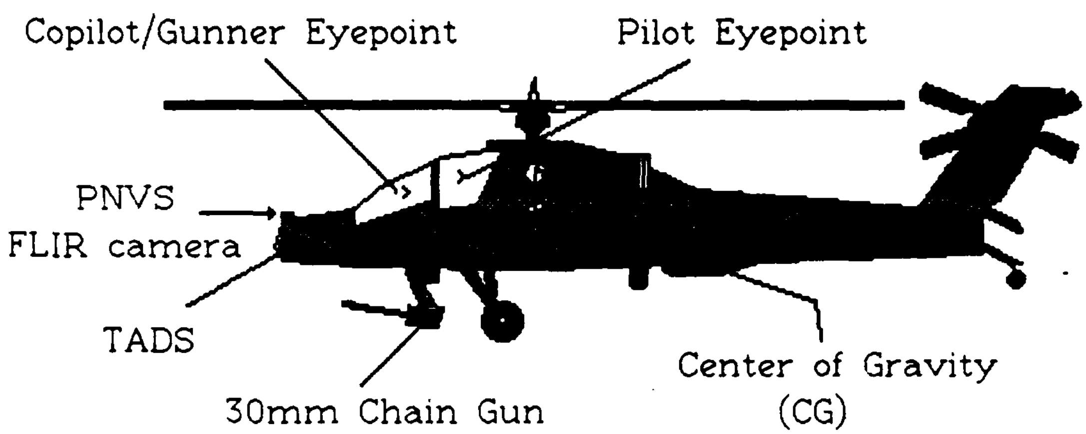

Figure 1.1 AH-64 APACHE

Common to PNVS and TADS operation is the Honeywell Integrated Helmet and Display Sight System or IHADSS which enables weaponary and optical sensors to be slaved to either crewmember's line of sight (LOS). Components include : crewmember helmets, helmet display units (HDU)

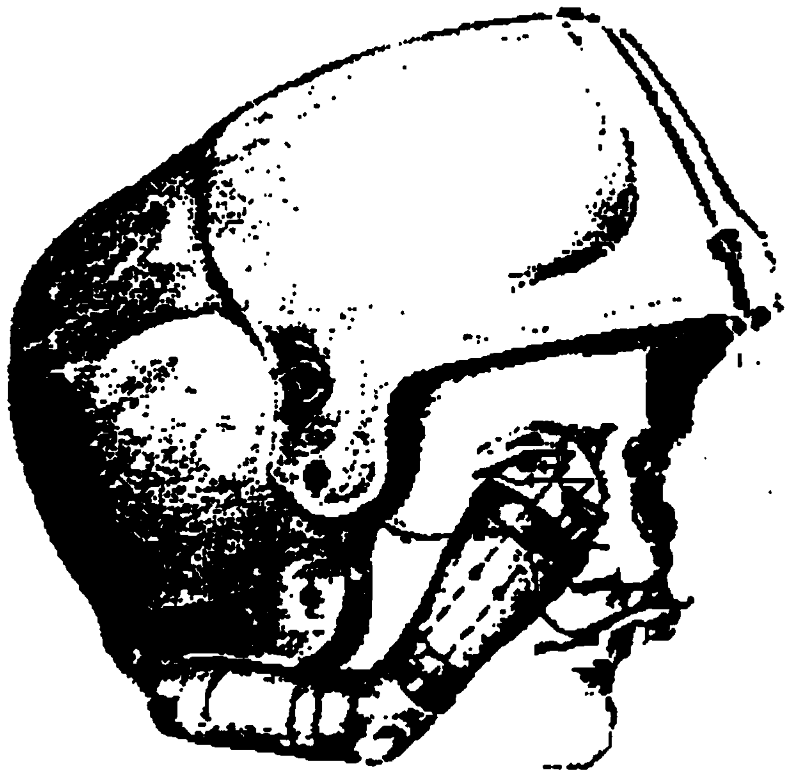

Figure 1.2 Helmet and HDU

mounted on the right side of the helmet, sensor survey units (SSU) behind each crewmember's helmet, boresight reticle units, display adjust panel, display electronics unit, and a sight electronics unit (SEU) that works in conjunction with the SSU's to determine the crewmember's line of sight. The IHADSS uses phased and timed infrared light beams from the SSU's which are sensed by detectors on the crew helmets in order to determine an accurate LOS for each crewmember [Ref. 2]. Collectively, the PNVS, TADS and IHADSS provide flight visibility enhancement and targeting capacity under day, night, NOE and adverse weather conditions.

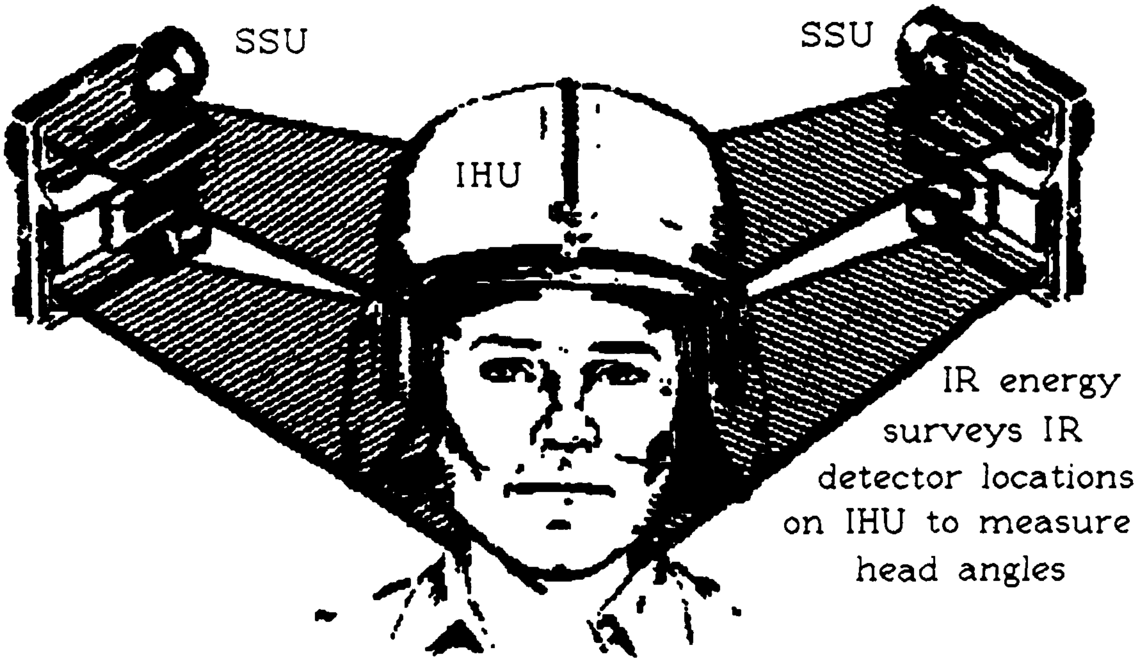

Figure 1.3 Sensor Survey Units

Without the proper training and guidance, crew performance in the attack helicopter is potentially affected if significant system obstacles can not be overcome. The use of the Apache's optical sensors with the IHADSS presents distinct learning difficulties for the crew to overcome if the threat is to be met, engaged and destroyed quickly. Specifically, viewing FLIR flight imagery from the nose of the aircraft into the right eye creates a displaced eyepoint ahead of and below the crewmember's nominal cockpit eyepoint. For more conventional weapons systems (especially on fixed-wing aircraft) that align weapon firing direction with the longitudinal aircraft axis, this is not a significant problem. However, in the Apache, area and point-target weapons (30mm turreted gun and Hellfire missiles respectively) have a directional, or 'off-axis' tracking capability. As the pilot or CPG tracks targets off-boresight or looks at large angles from the longitudinal aircraft axis, parallax effects increase; especially at close ranges and in hover. Other visual difficulties arise from the rivalry of views presented to each eye and from the quality of the FLIR visual image.

The U.S. Army received its first delivery of an Apache in January of 1984. Since that date, however, no quantifiable data is available to describe head tracking performance and its effect on flight control inputs or to define the operational limits of any of these systems. The Aerospace Human Factors Research Division at the

NASA/Ames Research Center was tasked to generate this information. The OATS experiment was the result of this effort.

The next section identifies the experiment goals and the directed efforts of this thesis. Section III defines the thesis scope followed by a background summary of pilot models and tracking subsystems in Section IV. An explanation of the tracking task and the types of flight trajectories needed to evaluate target tracking is given in Section V. The program used to generate trajectories is outlined in Section VI and its use in designing the specific OATS flight scenarios is explained in Section VII. After the scenario development, the algorithms used in calculating head tracking data such as the azimuth and elevation angles of the target line of sight are developed. Specific examples from the OATS scenarios are included in Section VIII. The integration of simulation facilities, hardware and software is then detailed in Section IX followed by concluding remarks about the design in Section X. Views of the simulator and visual scenes are in the Appendix.

II. OBJECTIVES

A. OFF AXIS TRACKING SIMULATION (OATS)

A five week duration piloted flight simulation using the Honeywell IHADSS was conducted at the Simulation Branch of the Flight Systems and Simulation Research Division. The Vertical Motion Simulator Interchangeable Cab (VMS ICAB) was used in a fixed-base mode due to VMS renovation. Twelve experienced AH-64 pilots were evaluated in the performance of manual and automatic flight tracking tasks in order to create a substantial source of head tracking data. This data could be applied to applicable fielded aircraft (AH-64) or serve as a potential base for the Army's Light Helicopter Experimental (LHX) program.

The researcher's specific goals were:

- Quantify Pilot Night Vision Sensor tracking performance using a helmet mounted display with appropriate flight and tracking symbology

- Identify the influence of head tracking on pilot control movements

- Identify maximum off-axis angles for target tracking within the mechanical constraints of the PNVS

- Study pilot workload and response during the task loadings

- Assist in channeling necessary research and development (R&D) efforts.

B. THESIS

The following list presents the specific goals of this thesis as a subordinate effort within the context of the above experimental simulation.

- Decide upon NASA computer software for OATS experiment and generate necessary modifications

- Improve computer simulation helicopter model for automatic flight

- Create appropriate target tracking flight scenarios in the simulator database terrain that will exercise the widest range of head velocities to be expected during operational target tracking

- Generate "perfect" head tracking data from the flight routes that is representative of the commanded profiles pilots would have to demonstrate in the aircraft body axis for ideal tracking performance.

III. SCOPE

In consideration of the exhaustive array of data to be recorded from trial simulation runs over the five week period, it was imperative that data collection efforts were not wasted collecting erroneous or unnecessary data. Also vital to the collection effort was a reasonable assurance that tasks given to the test subjects had a reasonable operational value. This meant that the generated flight scenarios, aircraft dynamics, and head tracking data output needed to closely approximate conditions expected by attack pilots in a target tracking task. Of course, constraints in achieving this realism would exist due to the simulation environment.

The OATS experiment was a study of the effects of visual cues and varying tracking geometries on target tracking performance. Subsequent human factors analysis of these effects is beyond the scope of this paper. This effort was directed toward the establishment of the necessary flight conditions and tracking tasks, and toward the design of proper algorithms to analyze the varying tracking geometries. Confidence in 'baseline' output data was essential to the future validity of tracking behavior and performance statements for the given scenarios.

IV. BACKGROUND

Investigations of target tracking weapons equipment and human performance is by no means a new endeavor. Prior work in this regard is clearly dependent upon the field of interest of the researcher. On one hand, performance models are attempts to describe pilot/gunner behavior in controlling vehicles or equipment in a tracking task. On the other hand, numerous efforts have been expended investigating the possible hardware configurations such as head down/up displays, helmet mounted sights, helmet mounted displays and eye trackers. At least one common focus is tracking accuracy improvement. Another is the desire to develop a mathematical representation, or 'black box' to describe dynamic input/output behavior of human operators.

A. PILOT MODELS

> A systematic approach to manned-threat quantification requires the development and integration of models for the weapon system and the human gunner into a composite analysis algorithm that can be used for analytical and predictive purposes. The accuracy and, hence, the confidence in the analysis algorithm is clearly dependent on the fidelity of the models used to describe the individual components of the weapon system and most importantly the human gunner(s). [Ref. 3]

Component models of 'the human gunner' include mathematical formulations for both eye and head control system dynamics. The phenomenal ability of humans to track moving objects is evident in that peak velocities of up to 400°/second have been observed in eye-movements. Eye and head movement trajectory traits are claimed to be intimately dependent upon target input characteristics, the instructions and training provided to the subject, and the experimental model in use. [Ref. 4]

Entire human gunner models have numerous characteristic approaches and are beyond the scope of this thesis. Of more recent success and worthy of mention, however, has been the use of optimal control theory in predicting human gunner tracking response. This approach, originated by Kleinman, Baron and Levison [Ref. 5] characterizes human response to control tasks through the solution of a linear quadratic optimal control and estimation problem subject to assumptions. This model also assumes that the gunner has internal models (perceived from his own training experience) for the target trajectory and the dynamic response of the system he is using to track. The gunner is also credited with being able to sense only the first derivative of any perceived variable (e.g. acceleration information is sensed from the gunner's perception of the target velocity). The complexity of such a pilot model can be disadvantageous from the point of view of computational simplicity.

B. TRACKING SUBSYSTEMS

Employment of target tracking hardware has also evolved into various schools of thought with regard to 'which is best' and what the most significant variables affecting performance are. Common to most configurations of aircraft today is the head up display (HUD) and the helmet mounted sight/display (HMS/HMD). A result of weapons delivery advances has been the development of off-boresight targeting capabilities (e.g. Hellfire missile) that allow directional tracking at large angles from the aircraft's longitudinal axis. It was suggested in the 1981 AGARD conference on the Impact of New Guidance and Control Systems on Military Aircraft Cockpit Design by a HUD manufacturer [Ref. 6] that HMS/HMD's were complementary to HUD's because they allowed discriminatory target designation way out of a HUD's field of view. Furthermore, it was felt that HMD's may really prove to be the best HUD formula for helicopters. Admittedly, further research in human vision was needed.

In Reference 7, investigation of a HMS/HMD was made both in flight and in simulation with the evaluation that no single system could meet all the helicopter's needs.

All other tracking investigations in the literature were found to primarily model helmet sights and not helmet displays. Most targets were generated by small patterns on a screen or light signals. Reference 8 details flight tests that evaluated off-boresight (off-axis) tracking angles and rates with a helmet mounted TV camera aligned with the sight. The results in this test indicated that these variables had little effect on sighting performance. These surprising results are compounded by the further claim that tracking error was greater at very small and large off-boresight angles than at 90° off-boresight. A 1978 investigation of Head Tracking at Large Angles from the Straight Ahead Position [Ref. 9] was performed with a sight aimed in broad off-boresight directions or quadrants. It was determined that best performance occurred when the head was pointing straight ahead, left center, and left down.

None of the experiments were found to have simulated FLIR imagery in a pilot's HMD (for tracking), as was to be the case in the OATS experiment. Simulations in the Apache Combat Mission Simulator (CMS) achieve a high degree of realism but do not send FLIR imagery to the pilot's eye [Ref. 10]. Even at NASA-Ames, previous use of the simulation cockpit for air-to-air helicopter handlings qualities evaluations with the IHADSS had used a transparent HDU monocle with only symbology to track targets ‘out the window’. A significant challenge therefore faced the developers for the OATS simulation in order to create a realistic tracking capability that matched that which is found in the Apache.

V. OATS EXPERIMENT

A. GEOMETRIC AND VISUAL CUEING

The thrust of the Off-Axis-Tracking Simulation (OATS) was to generate meaningful data on human head velocities while tracking with a helmet mounted display. Detailed examinations of the tracking geometry had to be performed. A secondary parameter of interest and just as relevant to overall tracking performance was the quality of the visual cues provided to the pilot during the tracking task. It was important to quantify both parameters in the determination of piloting trends and operating limits for the tracking task.

Target tracking performance is intuitively dependent on the target trajectory predictability, the display parameters, azimuth and elevation angles, and the intelligence gathered about the target. Predictability is perhaps the most direct measure of the tracking task difficulty. An aircraft in straight, level, unaccelerated flight is a highly predictable path and quite easy to track at normal engagement ranges. With jinking maneuvers added, predictability quickly erodes and the task is more difficult. Observation of the pilot's (the tracker) head movements in the cockpit would reveal similar variability in the azimuth and elevation rates while following the target with a HMD. With the assumption that the pilot can sense the first derivative of a perceived variable, it is plausible to make the following statement. If the second derivatives (accelerations) of the azimuth and elevation angles to the target are smooth (in a graphical sense), then the target trajectory is predictable because the pilot can sense angular velocities. Knowledge of the angular acceleration profiles of the target line of sight serves as an indicator of the tracking task difficulty. This concept is analogous to the rationale behind polynomial curve-fitting. The higher the order of the mathematical model that you perceive for a target's motion, the better your tracking performance. This suggests an upper limit on human tracking capability (and argues in favor of eye tracking because of the eye's capability to track faster than the head ...). [Ref. 11]

Knowledge of the target's shape and orientation affect tracking performance. If a subject is tasked to track a moving dot on a screen, no knowledge can be inferred of the future path of motion. With shape and orientation cues (e.g. a helicopter silhouette coming toward you) more information is available to assess the target's flight path.

Dynamic and geometric cues are not only important with regard to the target but also with regard to one's self. In a situation where the target remains stationary and the gunner moves (in flight) versus the exact reverse situation in which the target moves and the gunner is stationary, the relative geometries remain unchanged. In the first case (gunner moves), however, the gunner has anticipatory knowledge of his motions and, at least theoretically, can use this to his advantage in keeping locked on the target.

Peculiar visual problems are associated with HMD's but are compensated through training. The monocular FLIR view in front of the right eye makes it difficult for the pilot to adapt to the motion parallax that arises due to separate lines of sight from each eye. Another problem is the demand on the right eye to perceive both the flight and weapon symbology superimposed on the monocle while also attempting to view the terrain imagery from the FLIR. Switching visual tasks from the right to left eye also occurs to alleviate loading. The displaced eyepoint also causes a shadowing effect on objects when both eyes are being used. The intentional suppression of either symbology or imagery is yet another problem. These are all problems of binocular rivalry. Last, and not the least is the off-axis-viewing task already discussed. A further discussion of these problems can be found in Reference 12 from which this listing was taken. Although these problems may be minimized through training, it is not known what their impact is on mission task performance. It should be mentioned at this point that in light of these unresolved and complex problems, the OATS tracking scenarios needed to maintain a level of simplicity that would allow focusing on just a few variables at a time. As a result, trajectory predictability may suffer. Not all problems can be analyzed in a single simulation.

In OATS, all target tracking was decided to be continuous. No interruptions in the pilot's visibility was planned in order to allow a constant stream of data to be collected. Tracking durations were desired to be from twenty to sixty seconds in duration. Although unrealistic in most threat engagements (other than in a masked hover perhaps, a target would not be tracked for more than about five seconds), this duration insured the statistical significance of the time histories of the measured variables.

B. FLIGHT TRAJECTORIES

Analysis of the crewmember tracking task required the development of simulation trajectories that had a twofold design purpose:

- Develop a full range of head velocities that could be expected in operational tracking maneuvers

- Insure that a maximum, balanced coverage of possible head motions would be examined, i.e. tracking while looking down and to the right; down and to the left.

It was desired to look at flight and tracking performance for both moving and the stationary cases. Therefore, flight trajectories were broken down into three categories: (straight) rectilinear flight, curvilinear flight and hover. For the cases with the ownship in motion the target was stationary, and for the hover cases the target would be in motion. It was decided at a later point to create an air-to-air scenario in which both target and ownship were in motion.

It was also desired to analyze pilot flight and tracking performance in both manual and automatic (autopilot) flight. Automatic flight down a route would simulate the copilot/gunner's role of having to 'track' only. Manual flight would require controlling the aircraft *and* tracking down the same route that was just flown in the automatic mode. Of course, attempts by the pilots to fly those same nineteen routes manually (and track) would vary. This type of tasking simulates the workload that could be experienced by the gunner in the loss of the pilot, or the environment potentially faced in a single pilot LHX cockpit.

Aircraft handling qualities were therefore more important in the manual cases in which the pilot actually had control of the aircraft. The simulation helicopter dynamics for manual flight were produced from a resident software programs at the NASA/Ames Flight Simulations Branch called TMAN, CONTR2, and SMART. These programs approximated the stability and control characteristics of an Army UH-60 helicopter and were deemed adequate for use based upon their prior successful usage in air-to-air combat simulations, among others.

In the automatic flight cases, the overriding concern was not handling qualities because the pilot would be 'hands off'. Instead, navigation capabilities were paramount in order to duplicate the same paths for each subsequent pilot. A software routine called TDRIVE was used for the automatic flight path calculations. This program produced flight trajectories for both the ownship and target aircraft by means of a homing guidance algorithm and is discussed in the next section.

VI. TRAJECTORY PROGRAM

A smooth flight trajectory can be thought of as a concatenation of aerial waypoints. Navigation between the leg connecting any two waypoints is accomplished by homing guidance in which the aircraft is kept pointing toward the upcoming waypoint. The smoothness of the aircraft trajectory will be largely dependent upon the navigation code's flexibility in 'looking ahead' to sense directional changes. The trajectory program used in the OATS experiment, called TDRIVE, made use of these principles.

TDRIVE had been used in previous simulation experiments to 'drive' targets along desired paths across the database terrain (a nine kilometer square layout of geometric terrain representations). It was ideally suited, therefore, to reverse the concept of automatically driving the target to that of driving the pilot's 'ownship' also.

The incorporation of this program into use for the OATS experiment required significant modification. Before discussing how the flight routes were determined in the next section, this section describes the waypoint navigation (TDRIVE) program flow, execution and modifications.

TDRIVE generated a flight path between waypoints in the database for a simple coordinated helicopter. The predefined course to be flown in the simulator through the use of this routine required the user to input the x and y database positions to be flown toward (waypoints), the airspeed and altitude desired between any two waypoints, and the maximum bank angle that would be commanded to the helicopter during flight between those two waypoints.

The following steps outline the program flow for TDRIVE once a series of waypoints and flight data was input [Ref. 13].

1. Variables were initialized if necessary (first pass through).

2. New waypoint parameters were obtained as needed.

3. The desired heading to reach next waypoint was computed.

4. The roll angle needed to obtain the desired heading was calculated and used as a roll attitude command.

5. The aircraft roll dynamics were computed.

6. The pitch attitude was determined as a linear function of the airspeed.

7. Aircraft yaw angle was determined.

8. The aircraft altitude was adjusted as needed.

9. Aircraft airspeed was computed.

10. The inertial (earth axis) velocity components and position were computed.

As TDRIVE went through program execution, a limited, but sufficient amount of knowledge of the aircraft 'state' at any time was therefore known. This information would later be useful in determining Line of Sight relationships to the target from the aircraft for the pilot tracking task.

A sample two dimensional flight path plot from TDRIVE's output position variables is shown in Figure 6.1. The sequence of desired waypoints is also shown superimposed. This plot clearly shows the need for improvements upon the navigational aspects of the program. Satisfactory navigation between any two successive waypoints (a 'leg' of flight) was dependent upon numerous factors, to include: distance between waypoints, aircraft velocity, minimum turning radius, aircraft heading prior to entry upon that leg, and the maximum allowable bank angle for the velocity flown. These variables were decided upon only through numerous iterations and flight path graphing. (Actual use of the simulator cab during this design phase would have greatly aided and accelerated this process but its utilization for ongoing experiments was a deterring factor.)

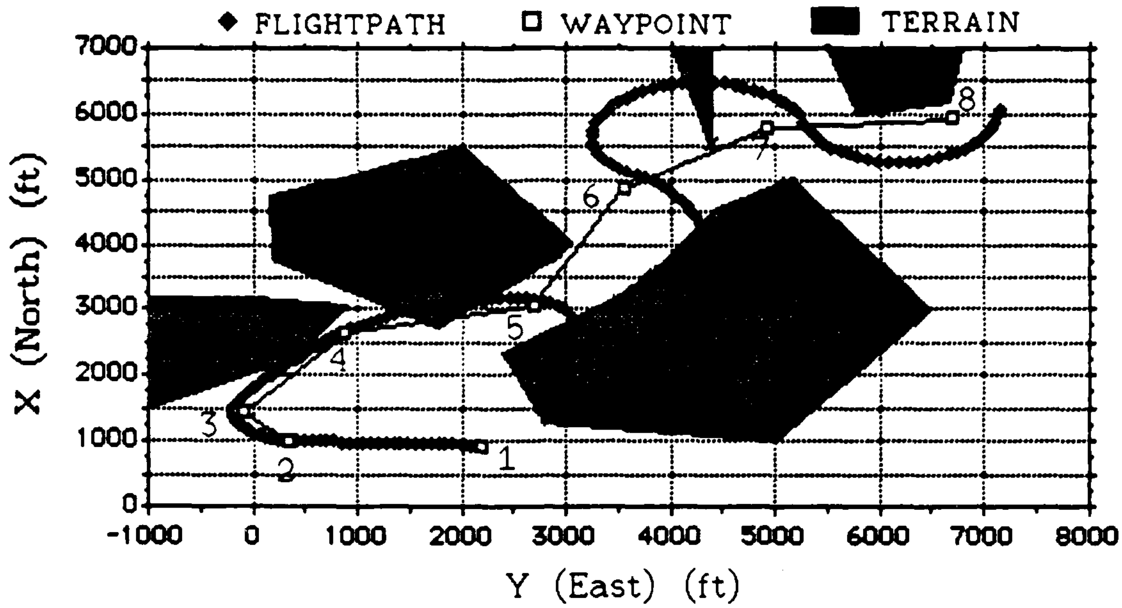

Figure 6.1 Uncorrected Waypoint Navigation

Two program variables that had a large impact upon waypoint navigation characteristics were TLEGMAX, the time on a particular leg of flight before a heading check to the next waypoint was performed and CAPTURE, the distance from the aircraft to the next waypoint that was required before transition would be made to another waypoint. Again, only through numerous iterations were these variables determined. The best capture distance was determined to be 300 feet for the aircraft velocities used

(70 → 120 knots) and the optimal TLEGMAX value was 80% of the time calculated to fly directly between any two waypoints in question. Incorporation of all these iterations gave results as shown in Figure 6.2 .

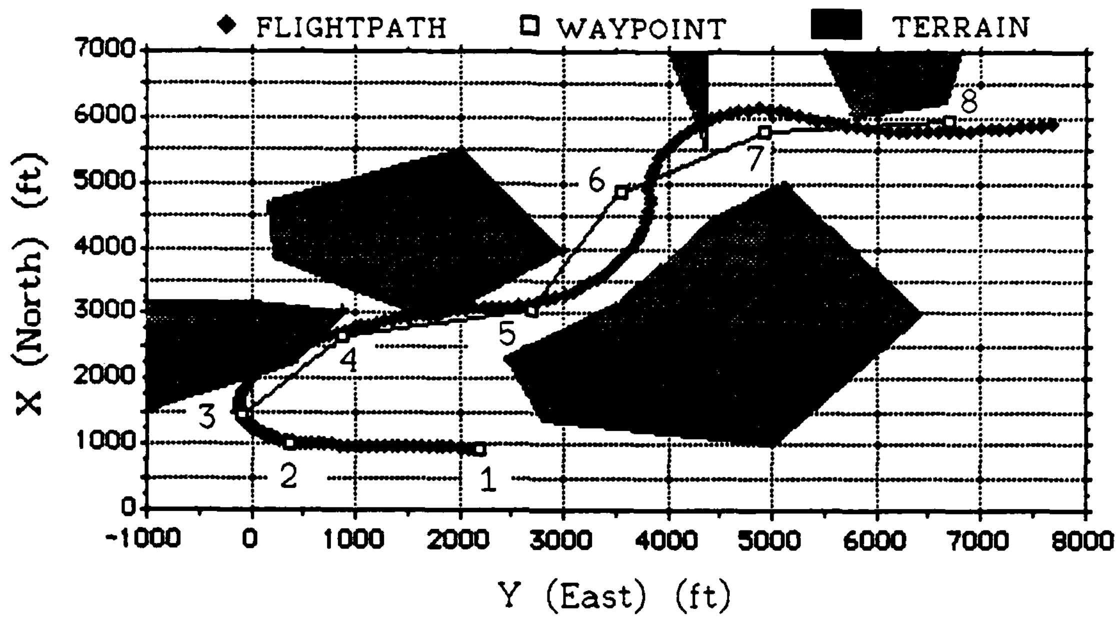

Figure 6.2 Corrected Waypoint Navigation

Satisfactory performance of the program in smoothly transitioning between waypoints was subjectively evaluated as a result of the author's personal helicopter pilot experience. The maximum bank angles to be commanded for tracking at the relatively low level altitudes to be flown was set equal to one-half the value of the velocity in knots. For example, at 120 knots it was felt that up to 60°

angle of bank was not extraordinary whereas at 70 knots, 35° was set as the maximum.

One last major consideration in the program output was evaluation of terrain clearance. Navigation would be relatively simple in a flat environment but this is not the case in the database nor in reality. The low-level flight environment made it difficult to match up aircraft altitude at any point in the program execution with the altitude of the terrain directly underneath the aircraft. This problem was solved through graphing techniques again as shown in the two figures already described and through careful, proper scaling of the database terrain onto these graphs. Most of the time, the simplest solution was to just keep on moving the waypoints until the flight path fit between terrain obstacles (or was above it). TDRIVE was modified so as to be completely interactive while going through these iterations.

Once a route's flight path was considered satisfactory, the data could be stored in a separate subroutine to be called when needed during the conduct of the experiment. The next section outlines the results obtained from designing the tracking scenarios with this trajectory program.

VII. OATS TRACKING SCENARIOS

Nineteen different flight routes, or 'Cases' as they were referred to, were developed for the pilots to fly. *Each* of these flight routes was flown in the two different modes: automatic and manual.

Recalling that the twofold purpose of the scenario development was generation of operational head tracking velocities and motions, certain choices existed as parameters to vary. The range of head velocities to be explored could be generated by varying the target's velocity and/or its range. Once the flight routes were established they would not be changed during the experiment. Therefore, variance of the ownship angular velocity would not be a factor in altering head velocities.

The target only moved during the hover and air-to-air cases. Both situations were chosen to have aerial targets, which for the most part, were assumed to have a relatively constant speed, as in a battlefield scenario, e.g. 100 knots. For the straight and curvilinear flights, the target was stationary when on the ground and when in an aerial hover. As a result, the target range was the variable of choice in generating different head velocities while tracking.

In order to achieve a balanced coverage of head motions, mirror image flights were created. For example, if a particular scenario forced the pilot to track a target that moved from his front to rear on his upper *right* side, then the mirror image flight scenario had the target moving from front to rear on his upper *left* side.

In all, the variables associated each routes' characteristics were (other than light intensity levels):

- Path : Straight, Curvilinear, Hover, or Air-to-Air
- Mode: Automatic or Manual
- Range: Close or Far
- Target Altitude : Up or Down
- Mirror Image : Left or Right

The above variables became the basis upon which codes were developed to identify the routes with a short representative meaning (other than a number) to assist the researchers and for computer coding ease. The first letter of the variable options was used to generate a five letter code. For example, route #2 was coded 'SAFUR' because it was a [S]traight path, [A]utomatic mode, [F]ar range, target was [U]p above ownship, and to the [R]ight.

Minor variations in the coding were necessary to accurately relay the intent of the route. Curvilinear routes ('S' shaped paths) were both close and far in range and so were labeled [V] for 'varying' in the third letter. The 'inverted' S shaped paths were labeled [I] in the same third letter. The letter [K] was substituted to represent 'Close' and [E] (for 'everywhere') when the target was on the left and right sides of the ownship. Lastly, [O] was used in the hovering cases when the target went obliquely from one side to the other and [P] for when it passed perpendicular to the ownship's front.

The correspondence between the routes' case numbers and codes are summarized on the next page. Cases 1 through 8 were the straight flight paths, 9 through 12 were the curvilinear paths, 13 through 18 the hover scenarios and case 19 was the air-to-air scenario. Each scenario is also mapped according to its path description in Figures 7.1, 7.2, 7.3 and 7.4 . The scenario case numbers and their respective codes will be referred to hereafter in order to identify each flight route. These codes were extremely handy as mnemonics during the experiment and in identifying data output and graphs.

The scenario numbers and case codings are paired in the list on the following page.

No.	Case:	No.	Case:
1.	SAKUR	13.	HAOUR
2.	SAFUR	14.	HAOUL
3.	SAKDR	15.	HAODR
4.	SAFDR	16.	HAODL
5.	SAKUL	17.	HAPUR
6.	SAFUL	18.	HAPUL
7.	SAKDL		
8.	SAFDL	19.	AIR2AIR
9.	CAVDE		
10.	CAVUE		
11.	CAIUE		
12.	CAIDE		

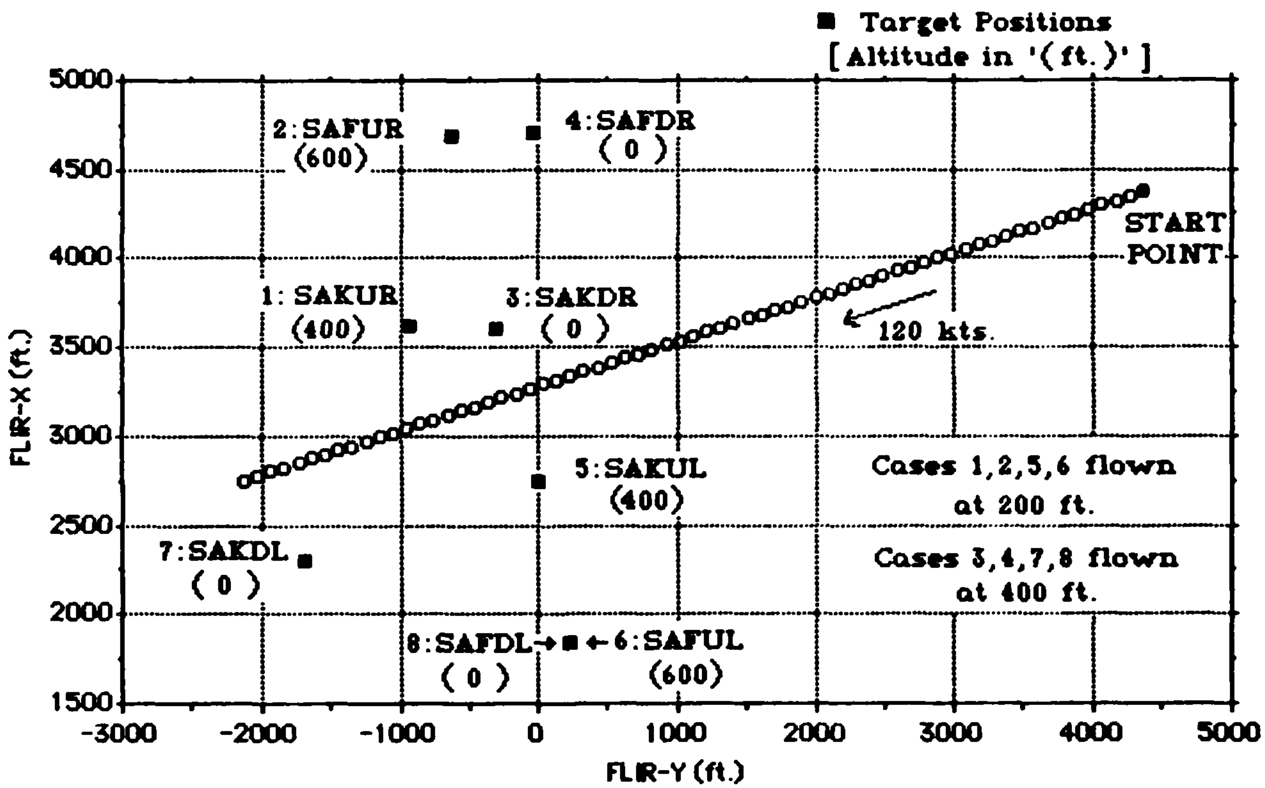

Figure 7.1 Cases 1 → 8 Flight Paths

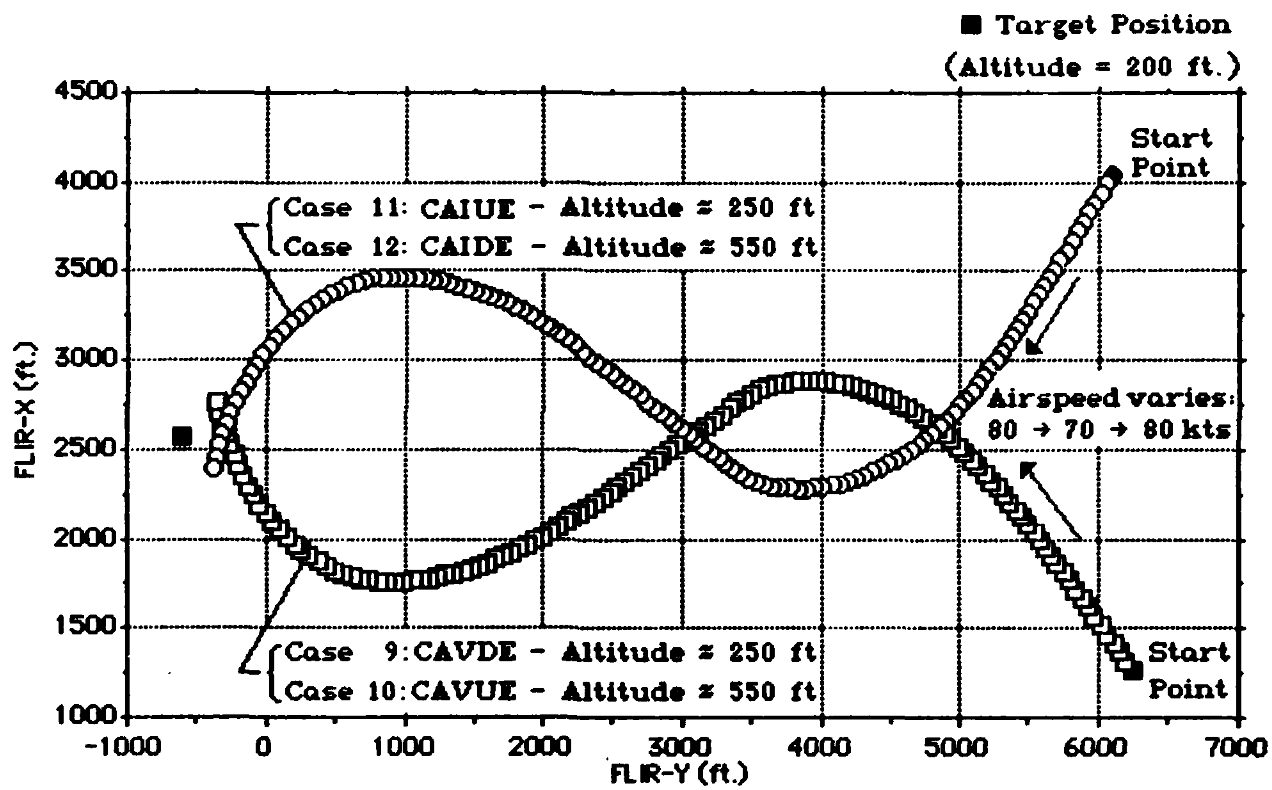

Figure 7.2 Cases 9 → 12 Flight Paths

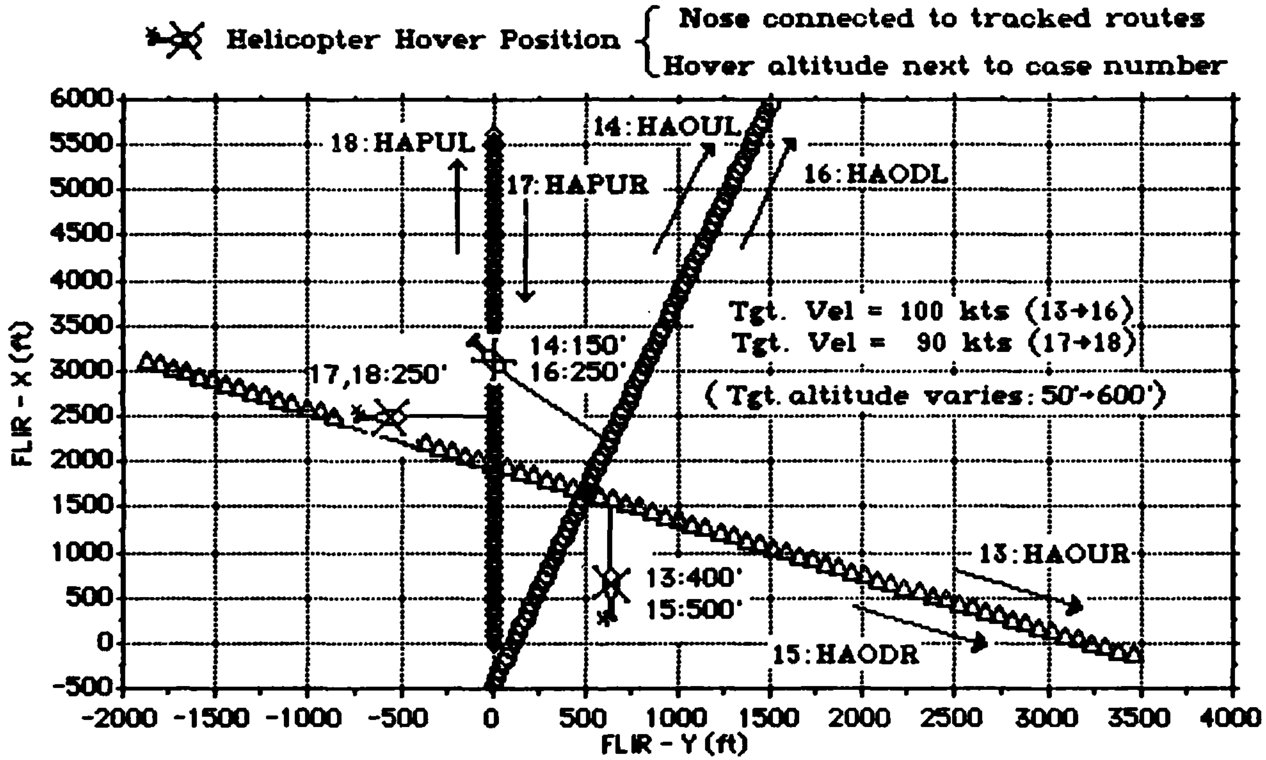

Figure 7.3 Cases 13 → 18 Target Paths (Hover Tracking)

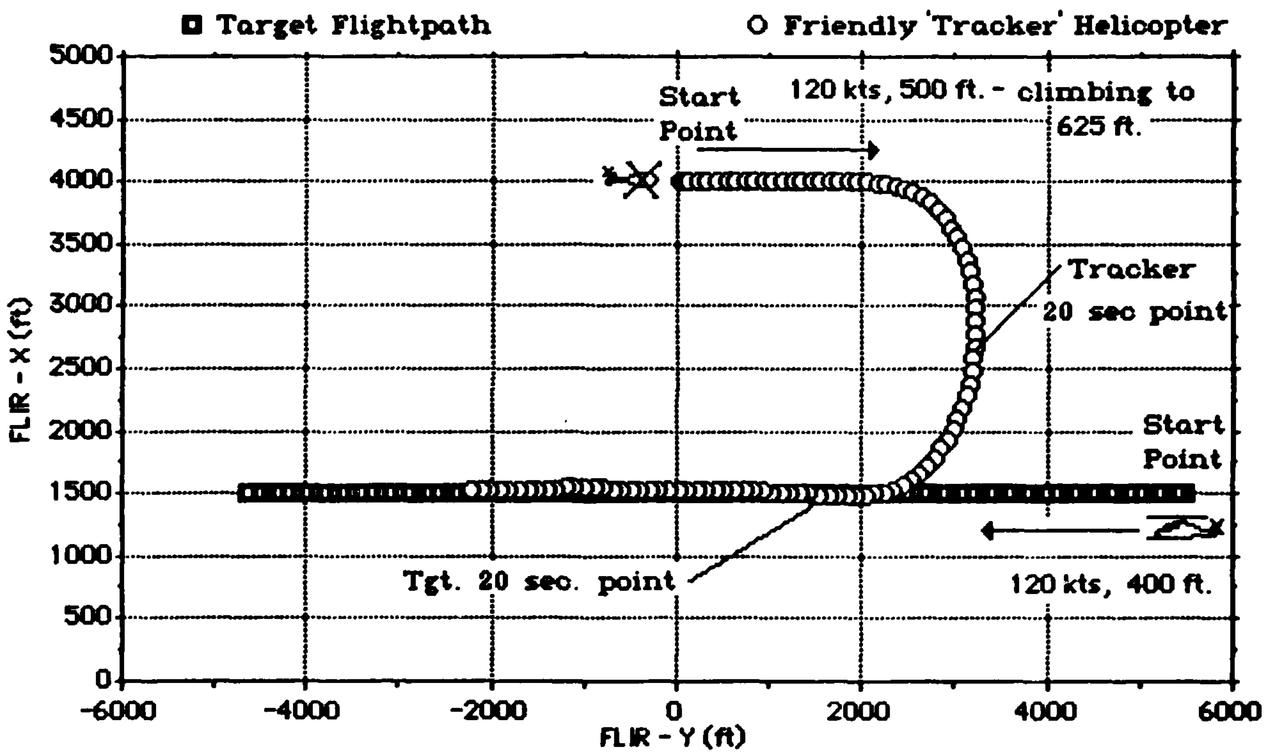

Figure 7.4 Case 19: AIR2AIR Scenario

VIII. TRACKING COMPUTATIONS

In order to measure pilot tracking performance, actual head azimuth and elevation data had to be compared to ideal, or baseline data for the scenario flown. Calculation of baseline data was also instrumental in insuring proper data collection algorithms were being used by the computers during the simulation runs. This section develops the necessary tracking data from an analysis of the Line of Sight (LOS) vector. This vector is defined as the view from the FLIR camera of the PNVS on the aircraft to the center of gravity (CG) of the target.

A. COORDINATE SYSTEMS

The relationships between the simulation database coordinate system, the aircraft axis system and the LOS vector can be seen in Figure 8.1 .

It is important to note that both coordinate systems are left-handed, orthogonal systems. Although contrary to usual orientation (positive Z axis downward), the left handed systems are utilized in the database to avoid handling negative values for altitudes. The North, East, Up (NEU) database axis represents a modified inertial, or 'earth' fixed axis whereas the aircraft's axis system is a

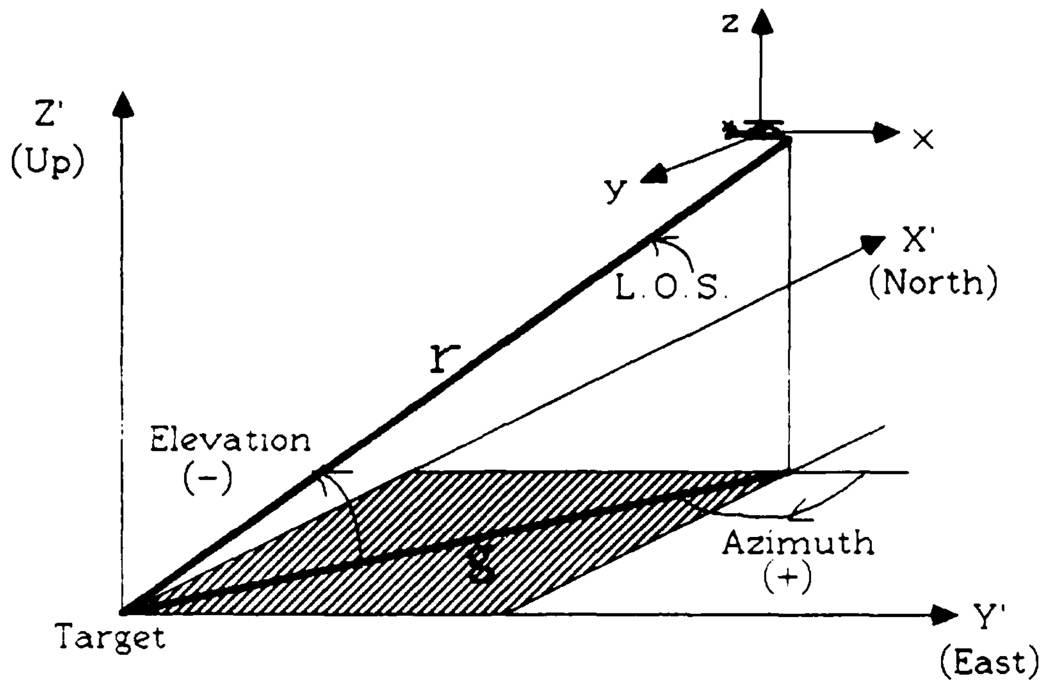

Figure 8.1 Database / Aircraft Axis Coordinate Systems

modified 'body' axis (z axis also up as with the earth axis). The body axis acts through the aircraft CG with positive x displacement forward through the aircraft roll axis; positive y displacement laterally to the right about the pitch axis; and positive z displacement upwards through the yaw axis (see Figure 8.2).

The FLIR camera position used in the simulation was 22.0 feet forward and 2.81 feet below the aircraft CG in the longitudinal plane. The position of the pilot's eyepoint was not relevant for LOS calculations (which originates at the FLIR camera) but was a factor in creating parallax whenever both eyes were active (e.g. day use of FLIR).

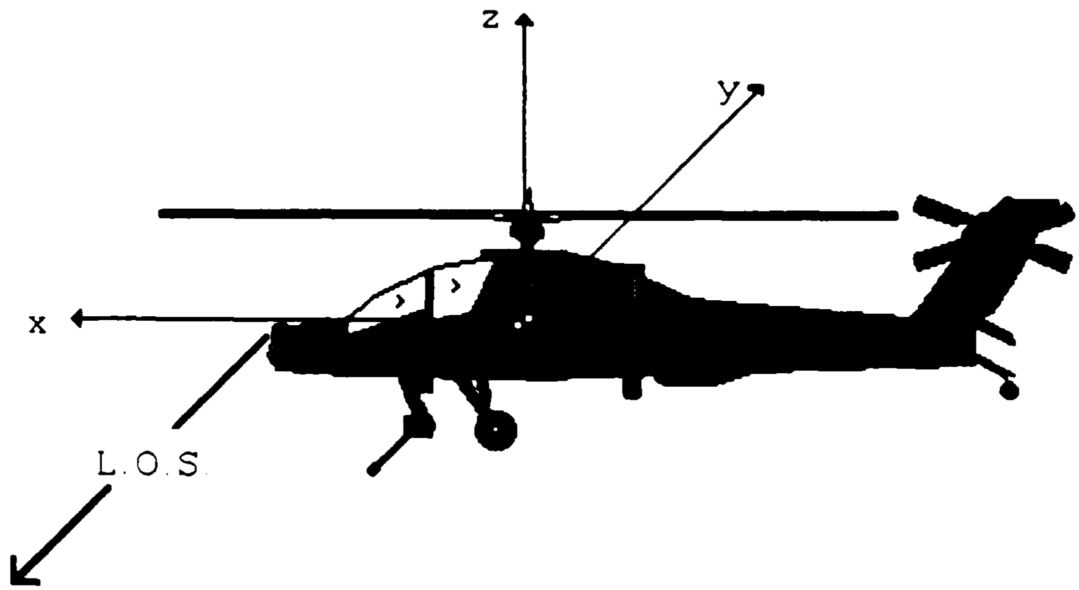

Figure 8.2 Modified Aircraft Body Axis

Because the LOS vector originates at the camera position and not the CG nor pilot's eyepoint, all calculations for tracking data had to account for this translation. The slant range to the target, then, is the length r, of the LOS vector and *not* aircraft CG to target CG distance. The length g, back in Figure 8.1, is the projection of the LOS vector onto the X'Y' plane of the earth axis.

Prior to establishing head/camera azimuth and elevation angles, it is now convenient to define the aircraft Euler angles, Ψ, Θ, and Φ. These are the respective aircraft yaw, pitch and roll angles that describe the orientation of the aircraft with respect to the earth-fixed axis (conventional right-handed axis systems—not the modified simulation left-hand systems). The order of rotation is important. The series of three consecutive rotations ($\Psi \rightarrow \Theta \rightarrow \Phi$) in the body axis are shown in Figure 8.3 .

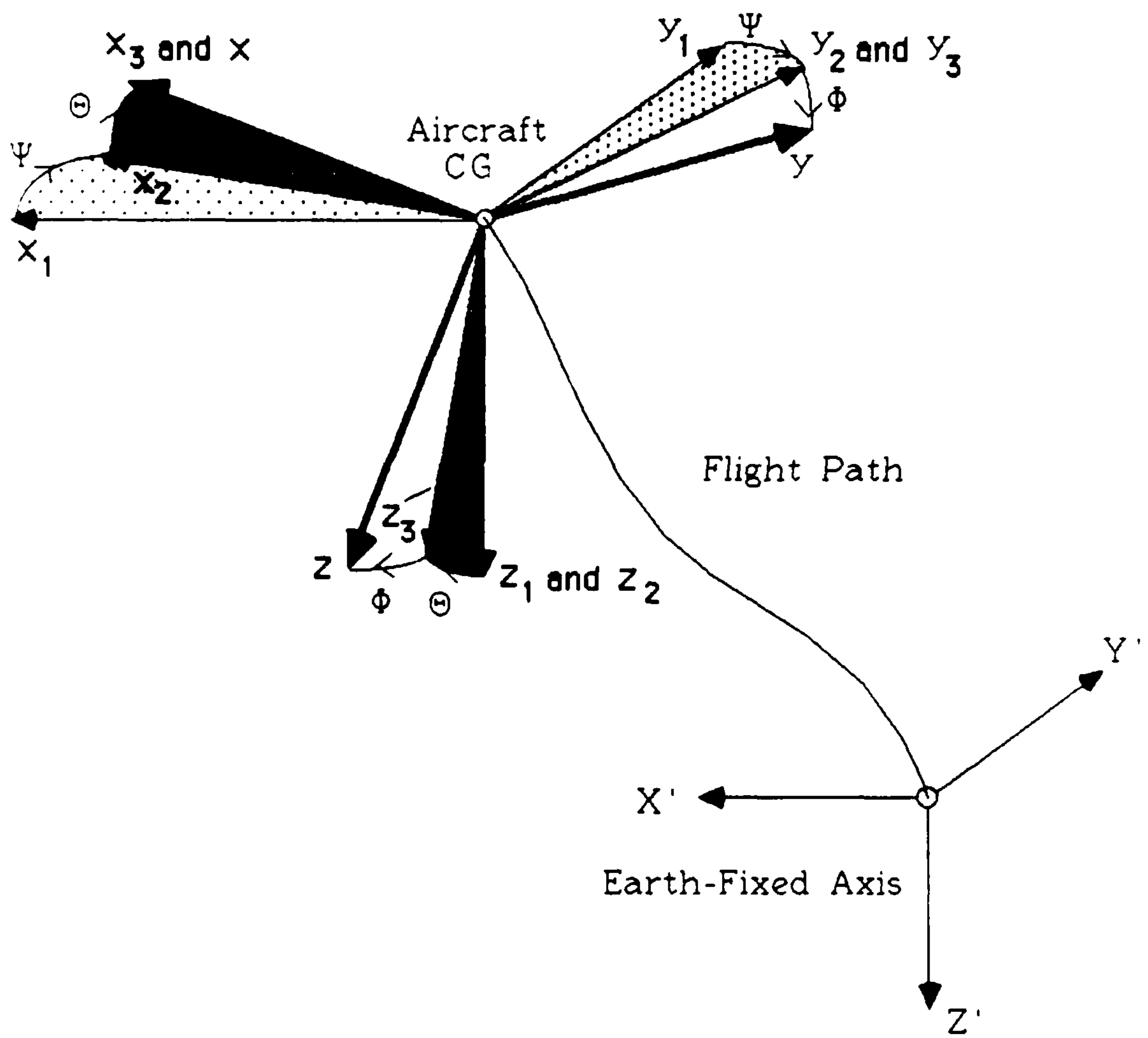

Figure 8.3 Euler Angles

Assuming the aircraft body axis to be lined up parallel with the earth axis, Ψ is the first rotation in the earth X'Y' plane about the z_1 body axis, Θ is the next rotation, about the y_2 body axis and lastly, Φ is the rotation about the body x_3 axis. The final body axis position is x y z.

Measurements of pilot head angles while tracking and slaved to the PNVS system are the same as measuring FLIR camera angles (assuming the pilot does not roll his head and that there are no delays in camera slew rates) because the FLIR image is sent to the HMD on the pilot's helmet. With the aircraft in any orientation in the database, the azimuth angle which the pilot must turn his head to see the target is the angle between two specific vectors. The first is the vector from the FLIR camera forward (parallel to the body x axis and 2.81 feet below), and the second is from the FLIR camera to the projection of the target CG on the horizontal body plane 2.81 feet below the xy plane. The elevation angle is measured from this azimuth direction vertically to the target CG.

It is much simpler, however, to translate the origin of the body axis coordinates to the FLIR camera position first. Then, similar to the Euler rotations Ψ and Θ, the azimuth angle is just the rotation of the x body axis to the projection of the target CG onto the body xy plane and the elevation angle is the vertical rotation of the x body axis to the target CG in the body axis system. Positive azimuth angles are to the right. Positive elevation angles are measured upwards.

B. VECTOR TRANSFORMATIONS

Once the LOS vector in the body axis has been determined, it is a relatively simpler matter to calculate the azimuth and elevation angles. First, however, the LOS vector is determined through two translations and one rotation involving both coordinate systems.

In the earth axis, by letting TPOSX, TPOSY, an TPOSZ represent the target position (CG) and XCGT, YCGT, and HCGT the aircraft location (CG), the LOS vector components from the aircraft to the target are:

$$\begin{aligned} TTX &= TPOSX - XCGT \\ TTY &= TPOSY - YCGT \\ TTZ &= TPOSZ - HCGT \end{aligned} \qquad \text{(eqn 1)}$$

This is the first necessary translation. As shown in Figure 8.4, this subtraction, in effect, moves the earth axis to the target CG and aircraft position is now described relative to the target.

In order to describe this vector in the body axis, it must be rotated through the *successive* aircraft orientation

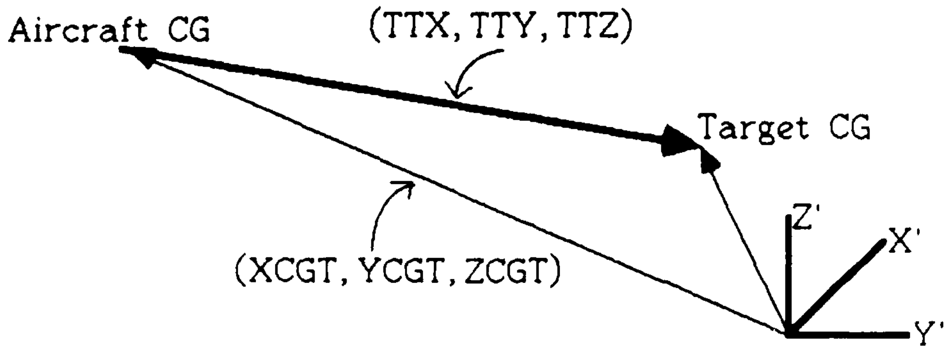

Figure 8.4 CG to CG Line of Sight (Mod. Earth Axis)

angles Ψ, Θ, and Φ that brought the body axis system into place (relative to the earth axis) This is accomplished through the three Euler transformation matrixes:

$$[\ \Psi\ ] = \begin{bmatrix} \cos\Psi & -\sin\Psi & 0 \\ \sin\Psi & \cos\Psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$[\ \Theta\ ] = \begin{bmatrix} \cos\Theta & 0 & \sin\Theta \\ 0 & 1 & 0 \\ -\sin\Theta & 0 & \cos\Theta \end{bmatrix} \qquad \text{(eqn 2)}$$

$$[\ \Phi\ ] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\Phi & -\sin\Phi \\ 0 & \sin\Phi & \cos\Phi \end{bmatrix}$$

The product of these three orthogonal transformations (making sure that the [Ψ] matrix is third, i.e., in order to multiply any column vector first) is

$$[\ \Phi\ ]\ [\ \Theta\ ]\ [\ \Psi\ ] = \begin{bmatrix} TT11 & TT12 & TT13 \\ TT21 & TT22 & TT23 \\ TT31 & TT32 & TT33 \end{bmatrix} \qquad \text{(eqn 3)}$$

where

$$TT11 = \cos\Theta\cos\Psi$$

$$TT12 = \sin\Psi\cos\Theta$$

$$TT13 = -\sin\Theta$$

$$TT21 = \cos\Psi\sin\Theta\sin\Phi - \sin\Psi\cos\Phi$$

$$TT22 = \sin\Psi\sin\Theta\sin\Phi + \cos\Psi\cos\Phi \qquad \text{(eqn 4)}$$

$$TT23 = \cos\Theta\sin\Phi$$

$$TT31 = \cos\Psi\sin\Theta\cos\Phi + \sin\Psi\sin\Phi$$

$$TT32 = \sin\Psi\sin\Theta\cos\Phi - \cos\Psi\sin\Phi$$

$$TT33 = \cos\Theta\cos\Phi.$$

The resulting matrix in equation 4 will hereafter be called the (Euler) Transformation Matrix, or [TT] for short. Premultiplication of any earth-fixed axis column vector by [TT] transforms its components into the equivalent body axis components. (Likewise, premultiplication of any body axis vector by the transpose of [TT] yields the earth-fixed axis equivalent vector.) This is true for conventional right hand orthogonal systems whereas left-hand coordinate systems are being used in this simulation. In order to transform (TTX, TTY, TTZ), the TTZ component in the North, East, Up (NEU) database is multiplied by −1 in order to establish a North, East, Down (NED) right-handed system. At this point the transformation matrix can be applied to yield a body axis *NED* CG to CG LOS vector, (TBX*, TBY*, TBZ*).

$$\begin{bmatrix} TBX^* \\ TBY^* \\ TBZ^* \end{bmatrix} = \begin{bmatrix} TT11 & TT12 & TT13 \\ TT21 & TT22 & TT23 \\ TT31 & TT32 & TT33 \end{bmatrix} \begin{bmatrix} TTX \\ TTY \\ -TTZ \end{bmatrix} \quad \text{(eqn 5)}$$

Multiplication of TBZ* by −1 will bring the vector back to the NEU axis system. The vector at this point represents the aircraft CG to target CG LOS *in the body axis*. Now that the first translation and the Euler rotations have been applied, all that remains is the second translation to bring the LOS vector in line with the FLIR camera (instead of the aircraft CG). The camera body axis x and z component distances of 22.0 and −2.81 feet, respectively, are subtracted.

$$
\begin{aligned}
TBX &= TBX^* - 22.0 \\
TBY &= TBY^* \\
TBZ &= TBZ^* - (-2.81)
\end{aligned}
\qquad \text{(eqn 6)}
$$

The final LOS vector from the FLIR camera is depicted in Figure 8.5 as (TBX, TBY, TBZ).

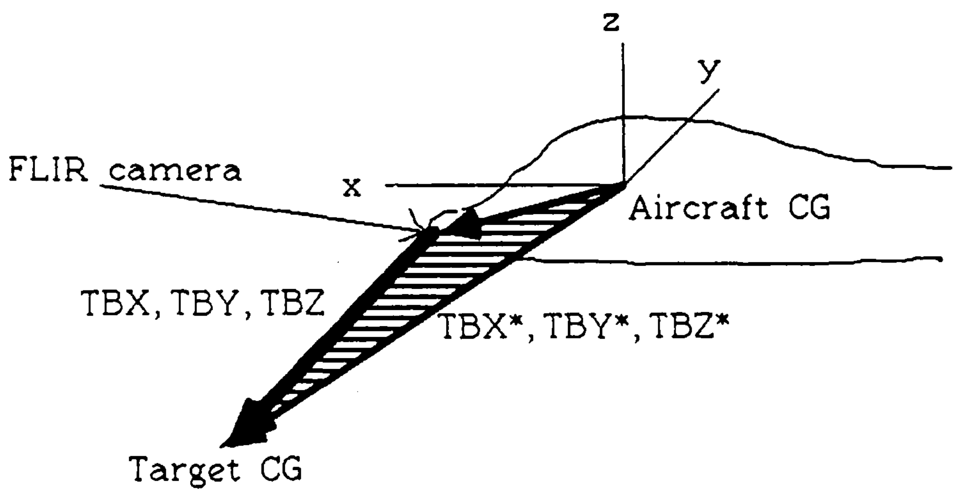

Figure 8.5 Final Line of Sight Vector

Determination of the azimuth and elevation to the target (AZT and ELT) is now a matter of using the components of the LOS vector as shown in Figure 8.6 where:

$$AZT = \tan^{-1}\left(\frac{TBY}{TBX}\right)$$

$$ELT = \tan^{-1}\left(\frac{TBZ}{g}\right)$$

and:

$$g = \sqrt{TBX^2 + TBY^2}\ .$$

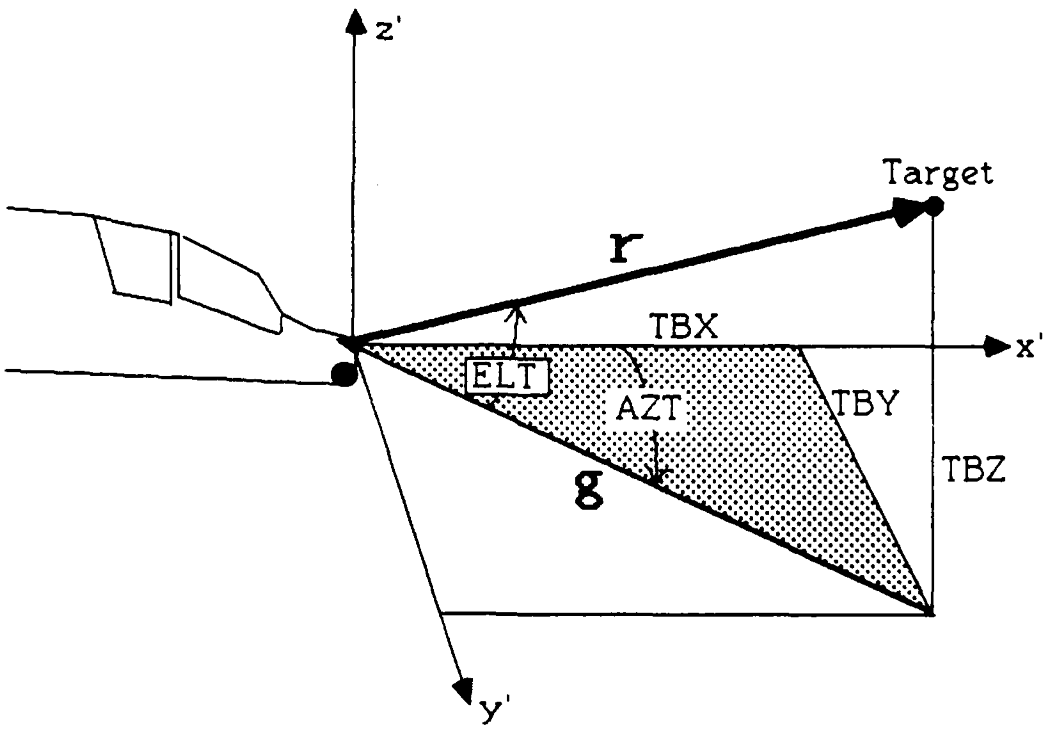

Figure 8.6 Sight Angles in Translated Body Axis

Care must be observed in these trigonometric calculations to insure the right quadrant is used. Azimuth measurements were made to be ± 180° whereas elevations ranged from ± 90°.

C. TRACKING CONSIDERATIONS IN OATS

Some of the considerations of the OATS experiment design with regard to target tracking need to be explained.

1. Roll Axis

Determination of the target LOS is made only through azimuth and elevation angles from the FLIR camera. Although the camera is driven by the pilot's head position in the cockpit, only the head azimuth and elevation angles are relayed to the camera. No information about the pilot's lateral head tilt (roll) is used in the LOS determination. Head roll may facilitate fixation on the target but must be avoided if it brings the helmet out of physical constraints for the cockpit sensors (SSU) that measure the helmets position. It is also assumed here that head roll introduces erroneous helmet position cues to the SSU's even if within the constrained cockpit region.

2. Head Angular rates

The rate of change of the LOS vector in both the azimuth and elevation directions was determined by numerical differentiation of the time history trace of the azimuth and elevation angles for each route. Analytic determination of these rates was determined to be unreasonable given that the computational facilities were available to evaluate them numerically. Because the flight scenarios were designed to yield continuous tracking tasks, no discontinuities were expected in the head azimuth or elevation angles that would affect numerical differentiation.

In any tracking scenario the pilot obviously does not turn his head in one direction, e.g. azimuth, and then in the other in order to follow the target. The action is combined diagonally in the same sense that the shortest distance between two points is a straight line. The combined angular rotation of the pilot's eyepoint (the optic rate, or rate of change of optical position) is a function of the azimuth and elevation rates, and, although they are perpendicular components, there is a problem of scaling in the vertical direction. The simplest way to explain the need for a scaling factor is the analogy that 1° of longitude at the equator delimits a greater distance than 1° of longitude at the North Pole [Ref. 14]. The scaling factor in determining the optic rate involves the elevation angle and is $\cos^2(ELT)$.

$$\dot{OP} = \sqrt{\dot{AZT}^2 \cos^2(ELT) + \dot{ELT}^2}$$

Therefore, as the head elevation angle increases, the contribution of the azimuth rate to the optic rate is lessened.

3. Target Detection / Acquisition

Prior to actually tracking a target, the pilot/gunner must have already detected and acquired it. This experiment did not examine the interplay that these actions would have had on performance. For example, when a target suddenly appears to the pilots right front view, some may prefer to turn the aircraft towards the target first, others may feel comfortable immediately acquiring the target and then turning the aircraft as needed. In order to standardize the pilot taskings, the target was identified to the pilot prior to the start of the run. This posed a problem to a few of the pilots at the beginning of some of the curvilinear scenarios because the target was hard to identify at long ranges due to the lack of resolution in the database image. This problem usually disappeared as soon as motion began for the run.

D. EXAMPLE RESULTS

The graphical outputs and computer program listing used to calculate and display all tracking baseline data is contained in a separate report to be published at a later date. Tracking Case #18 (HAPUL) is used in this section as an example of the data output. This was a very simple tracking scenario to follow and, as such, serves as a good graphical representation of the line of sight calculations. A series of four graphs depict the output of the main parameters of interest for this tracking scenario.

Case 18 was a hover tracking task. As can be seen back in Figure 7.3, the gunner was hovering, pointing East on the database and the target flew from the South to North, perpendicular to the gunner's front. (The target aircraft was also above the gunner's by almost 300 feet initially and descended to a level altitude of about 40 feet above the gunner after 20 seconds.)

Figures 8.7 and 8.8 show time histories of the azimuth and elevation angles to the target from the FLIR image presented in the gunner's right eye if perfect tracking would have occurred. Also shown are the azimuth and elevation rates, or head velocities, in degrees/second.

In Figure 8.9 the combined effect of the azimuth and elevation rates is shown as the overall head velocity, or optic rate (because the eye moves in unison with the head in the HMD). Figure 8.10 depicts the slant range and database (NEU) body axis distances to the target as a function of time.

It is interesting to note the characteristic shapes of the azimuth and elevation angle profiles in the first two graphs.

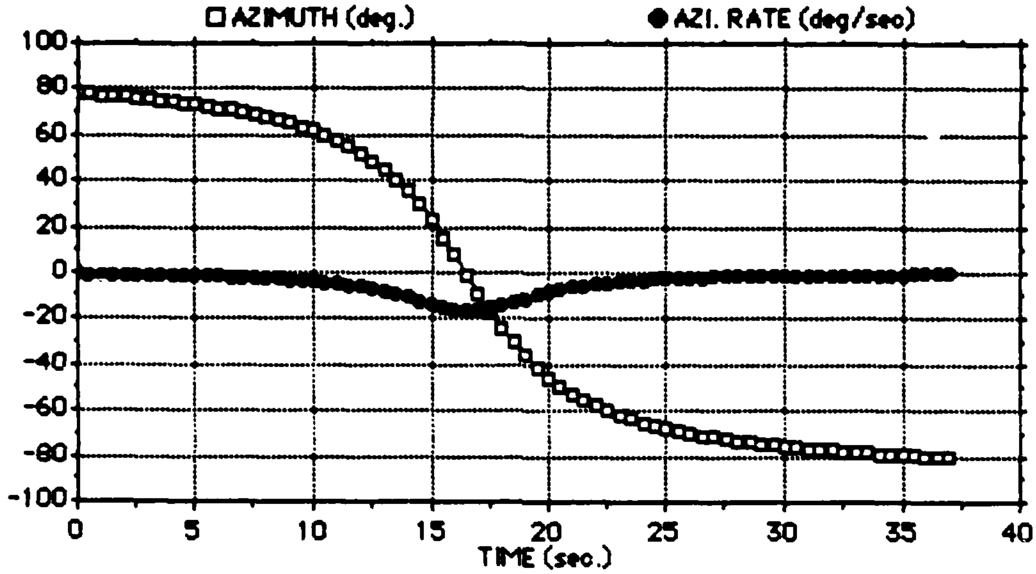

Figure 8.7 Case 18: Head Azimuth and Azimuth Rate

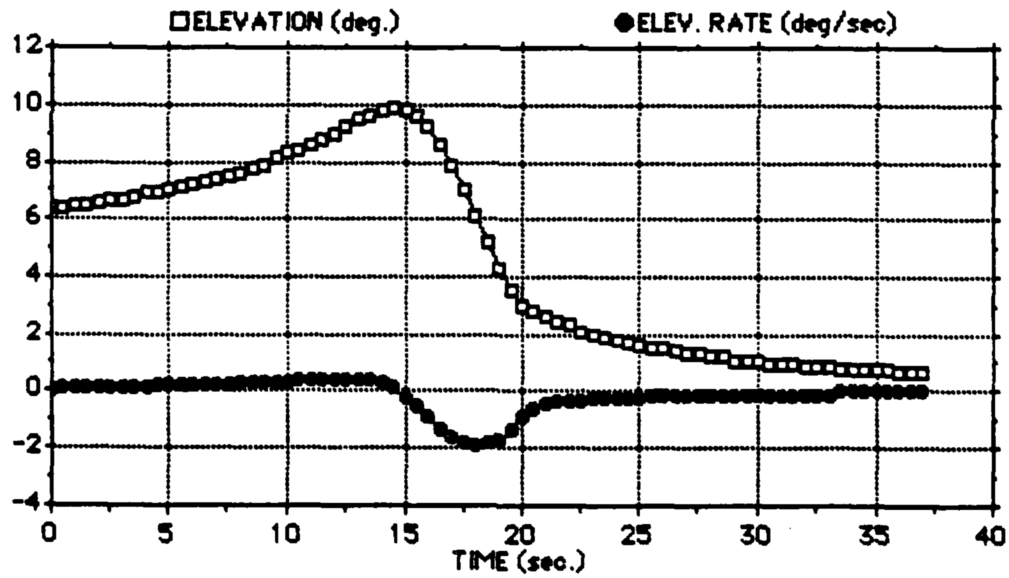

Figure 8.8 Case 18: Head Elevation and Elevation Rate

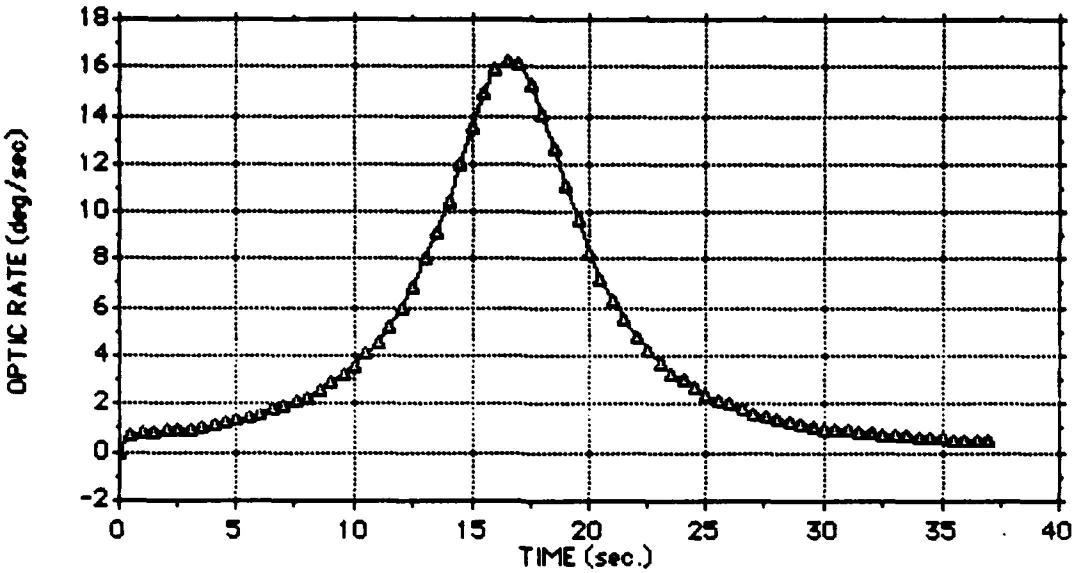

Figure 8.9 Overall Head Velocity (Optic Rate)

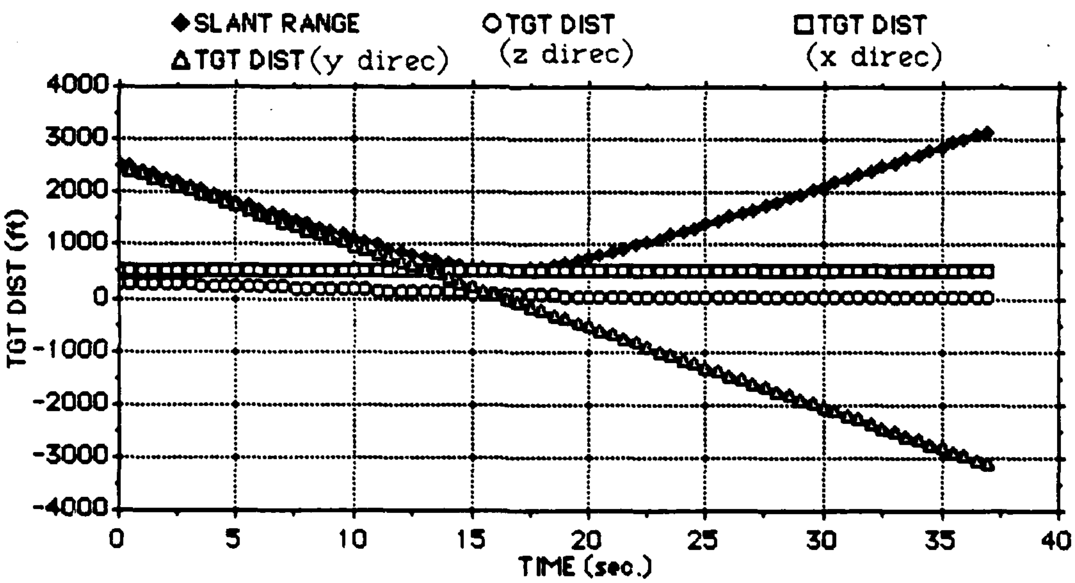

Figure 8.10 Modified Body Axis Distances to Target

Due to the geometric simplicity here, it is relatively easy to see how the elevation profile is bell shaped if the target flies a level path with the bell peak at the instant the azimuth angle is changing most rapidly. This is not exactly the case here, however, because the change in altitude of the target shifts the elevation profile somewhat.

Also interesting is the fact that the head elevation rate peak velocity does not occur at the minimum slant range to the target as does the head azimuth rate. This again is due in part to the descent profile of the target. Although subtle, the point here is that the overall optic rate peak velocity need not occur always at the point at which the target is closest (where slant range is minimum). Peak head velocities are a complex geometric interplay of both the target and gunner's motion, orientations and distances.

IX. SIMULATION DESIGN AND INTEGRATION

With the flight scenarios planned and tracking data calculations coded, the next phase became one of integration of facilities and software. These steps are briefly mentioned in this section.

A. TEST CELL MATRIX

The test cell matrix was the match-up of the twelve pilots to the scenarios (cases) they would fly. Approximately three pilots cycled through the simulation runs each week of four active weeks of data collection (the first week was set aside for hardware installation and checkout). It was deemed more important in the experimental procedure to evaluate each pilot fully across all nineteen automatic and manual (thirty-eight total) runs than it was to have each flight scenario fully tested by the twelve subjects. The order of flight cases presented to each pilot was arranged randomly each day to lend variety. The predictability of trajectories, unfortunately, could not be reduced once the scenarios became familiar. The pilots were always given the automatic version of a flight route first, followed by their own attempt to track the target and manually fly on the next. This sequence was structured in order to minimize flight path deviations from the automatic version of that same run. In this manner, it was hoped that a more valid correlation between task loads (track or track and fly) could be evaluated from the data.

B. FACILITIES / EQUIPMENT

1. Cockpit

The cockpit panel was not a factor in this simulation due to the use of the HMD for all tasks (video display units were not presented as are available in the A, ache). The glare-shield served to mount the boresight reticle unit for the IHADDS.

Standard (generic) cyclic and collective sticks were used with the only modification being the installation of switches for boresighting.

The major cockpit modification was the installation of the Honeywell IHADSS. Pilots brought their own helmets and a HDU was on station from Honeywell. The SSU's generate pulsed infrared signals into the cockpit headspace in order to determine helmet position and hence, LOS information. SSU's were mounted on the vertical seat posts behind the pilot and adjusted and set by Honeywell to imitate the 'motion constraints box'. This theoretical box represents the physical limits within which the infrared detectors are in position to receive infrared energy emitted by the SSU's. Head movement outside of these constraints 'froze' the LOS and stopped data collection. The AH-64 motion box is shown in Figure 9.1 .

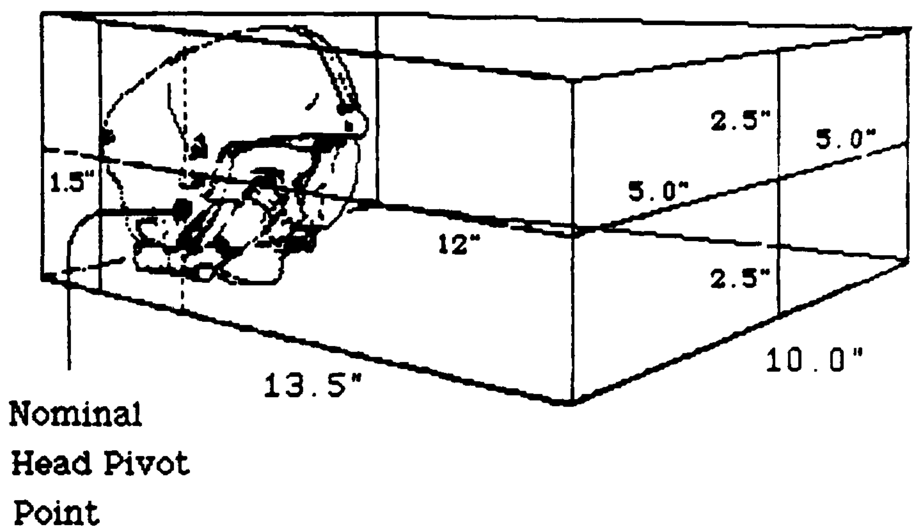

Figure 9.1 AH-64 Motion Box

2. <u>Windows / Field of View</u>

The normal computer generated imagery (CGI) within the VMS ICAB is displayed on three centerline screens that are 46° wide by 34° tall. A fourth chin bubble window, 24° by 34°, is normally in position to the lower right and active for helicopter simulations. The database view from this fourth window was eliminated and instead, the view from the nose mounted FLIR camera ahead and below the pilot was sent along this window's channel to the HDU lens.

The windshield FOV was small and significantly less than that experienced in any actual helicopter. The HMD, however, was set to the viewing limits of the AH-64 PNVS. Both TADS and PNVS field of regard (FOR) limits are shown in Figure 9.2. The instantaneous HMD FOV within

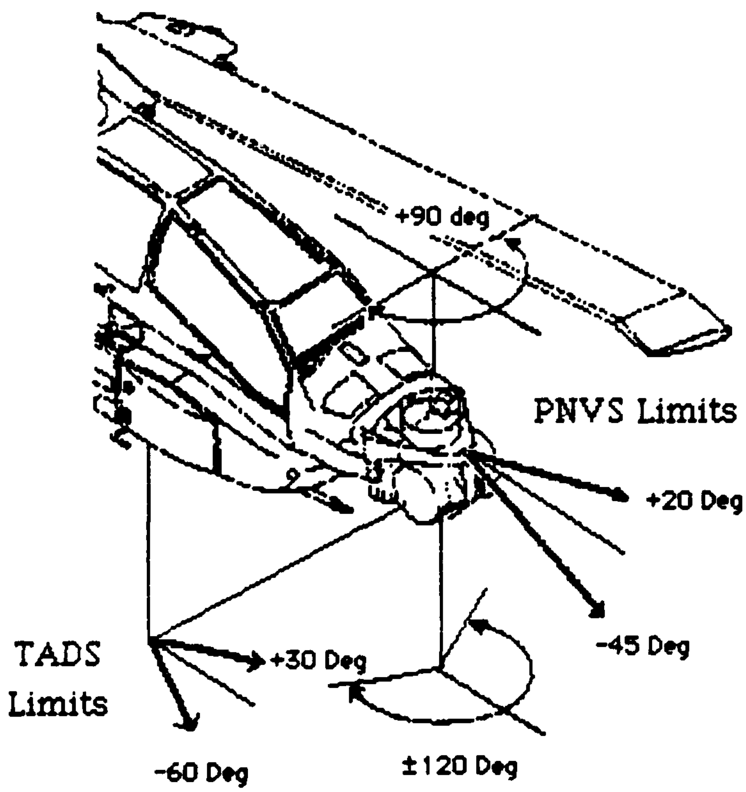

Figure 9.2 TADS / PNVS Gimbal Limits

the PNVS FOR is 40° horizontal by 30° vertical. The disadvantage of interrupted external views of the database because of the window supports was not a problem within the PNVS FOR taken from the fourth window viewpoint. This was a significant victory over a normal simulator viewing deficiency.

3. <u>Symbology</u>

The flight symbology that was superimposed on the HMD monocle is shown in Figure 9.3. A description of each item number follows.

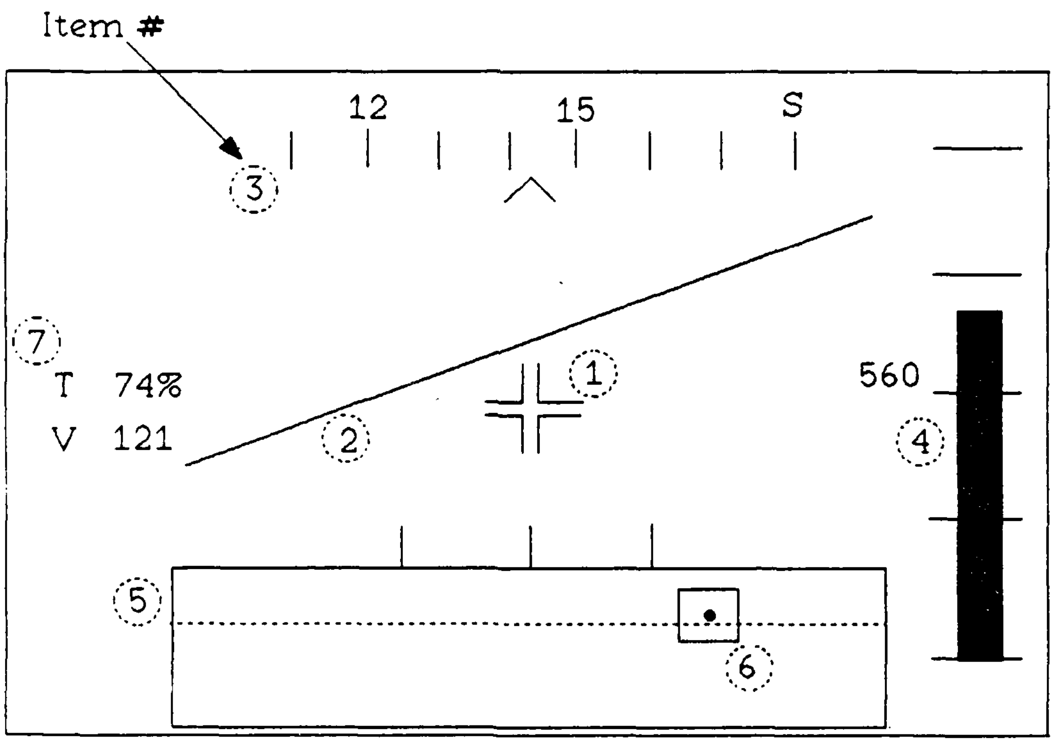

Figure 9.3 HMD Symbology

1 – Target cross hairs (and level flight reference for # 2)

2 – Horizon indicator(Indicates both pitch and roll, e.g. here the aircraft is banked 20° right and pitched down 7° due to forward velocity)

3 – Aircraft heading (read under arrow, e.g. 143°)

4 – Aircraft altitude in feet above database ground reference. Each tick on vertical scale is 200 feet.

5 – Field of Regard (FOR) for *target cross hairs*, e.g. slightly smaller than FOR for PNVS because the cross hairs can go up to the edge of this box. (The pilot can see beyond where he can track at the limits.)

6 – PNVS FOV as displayed in the HMD reticle. This FOV is positioned within the FOR (#5) relative to the pilot's line of sight, e.g. here the pilot is looking ~ 45° to the right and ~ 3° above the aircraft body axis at the FLIR camera position.

7 – Digital percent torque and velocity (knots) readings.

4. Motion

The inability to obtain use of the motion base potentially limited the simulation fidelity. Visual cues were addressed but motion cues were nonexistent. Richard S. Bray provides excellent insight to the issues of visual and motion cueing in helicopter simulations at NASA/Ames in Reference 15. Motion cueing for simulation is necessarily included in all handling-quality issues. It is assumed here that this capability is relevant in tracking performance also. According to Bray, tracking performance improved with motion fidelity in previous simulations.

5. Control room

A control room off to the side of the ICAB in use for the experiment provided audio-visual interaction with the subjects. Television monitors recorded the center screen CGI view along with an inset of the independent view that was presented to the pilot's HMD.

Two-way communication was available through the pilot's helmet and speakers. All control and data acquisition was performed from within this room.

6. Hardware / Software

Diagrams of the hardware and software integrations are shown in Figures 9.4 and 9.5 respectively. These arrangements are a significant simplification of the OATS technology and is entered to give an idea of the interplay between some of the hardware and software discussed in this report. A description of each component is beyond the report's scope.

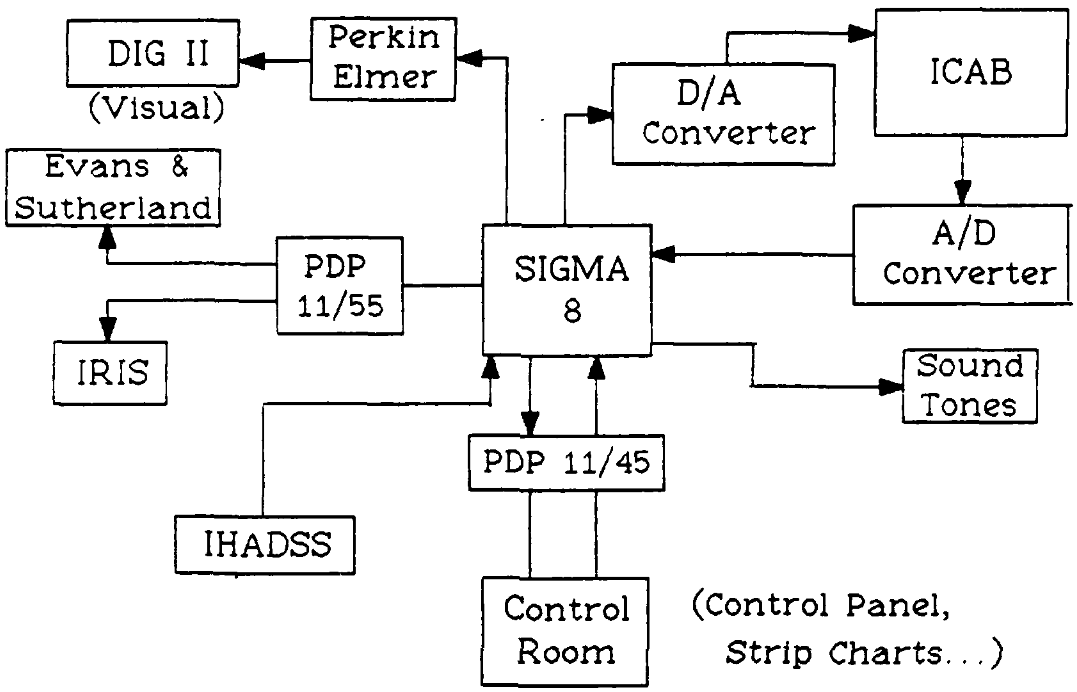

Figure 9.4 OATS Hardware

7. <u>Simulator</u>

An important integration concern was matching the simulated FLIR image refresh rate with that of the CGI scene-generation. The visual scene was reconstructed approximately every 100 milliseconds and the computational rate for the helicopter dynamics was 25Hz (40 milliseconds). Because the scene may be generated at the beginning or

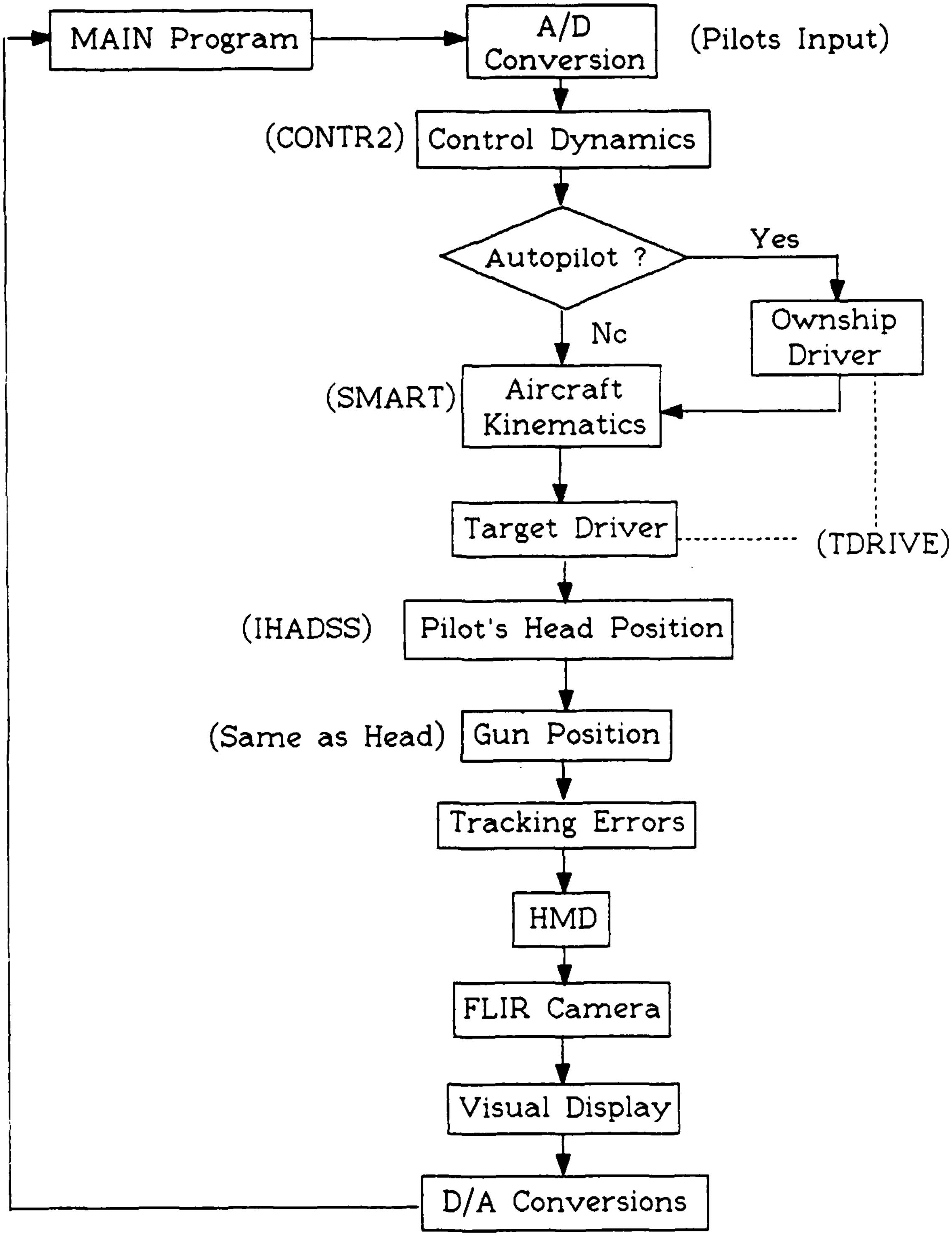

Figure 9.5 OATS Software

end of a calculation, the range of 40 milliseconds produces an average transport delay (pure delay until response) of 120 milliseconds.

The CGI screen initially presented unexplained, high rate of bank images during the curvilinear flight routes. The roll velocity in the helicopter automatic flight model, TDRIVE, was designed to result in a critically damped second-order response to roll commands. The dynamic gains used to achieve this response had to be adjusted in the programming in order to present a realistic roll rate in all the flight scenarios.

C. OATS EXPERIMENTAL PROCEDURE

Daily simulation test procedures consisted of system checks, pilot orientations, actual runs and data management.

Prior to the start of each day of tests, the computer software and ICAB workings were validated. These checks were performed by the SYRE (software engineers) console operator and various support personnel on an as needed basis.

The pilots were briefed each day as to the order of rotation and familiarized with the task descriptions. Each pilot spent approximately one hour in the cab at any one time. Familiarization practice was given to new arrival pilots each week to become accustomed to the helicopter model, database terrain and the FLIR image simulation. (Valuable feedback was continually offered by the pilots due to their significant instructor pilot experience.)

Each flight tracking scenario period began with a boresight of the pilot's helmet and display. This step was crucial in exacting accurate and significant data from the runs.

Once the console operator positioned the aircraft at its starting point for a given case, the pilot sought out the target's initial position and acquired the target in his HMD. Instructions were given to each pilot immediately prior to each run that identified the type of scenario and target location. In the 'freeze' condition before each run it was difficult to spot the target against the terrain. (Colors were varied for the target to bring out its image in the low resolution scene because of the ranges involved at the start of each run. Further acquisition was aided by making ground targets out to be helicopters because the rotating blades were usually visible where contrast was poor.)

Pilot workload opinions were randomly solicited after termination of runs and recorded. These could later be matched to the video recordings of that particular run if necessary.

Tracking data was collected in the control room during each run on magnetic tape, strip chart summaries and VERSATEC printouts of summary data. The magnetic tape (RUNDUM) data was the primary recording of the time histories of all variables. The VERSATEC printout and strip charts were an 'on-hand' tool used to ensure proper operation of the runs.

X. CONCLUDING REMARKS

The stated goals of this thesis to create automated simulation flight routes and to determine all baseline head tracking data associated with those scenarios was accomplished for the OATS experiment in the manner described within this report. A separate report will contain all graphical results and computer program listings. Size constraints prevent their inclusion in this report. The information point of contact at NASA/Ames Research Center is LTC C.T. Bennett, Ph.D., MS 239-3, Moffet Field, Ca 94035.

A. IMPLEMENTATION

The major success in the the Off-Axis-Tracking Simulation was the integrated use of hardware that produced a realistic replication of the night vision system found in the AH-64. Pilot comments were all favorable in this regard. The ability to create a simulated FLIR imagery on a helmet mounted display that is slaved to a pilot's line of sight in a CGI flight simulator is significant advance in target tracking simulation. It can only be expected that visually coupled systems and simulator capabilities will continue to advance and grow in experimental importance.

Conversely, however, the most noteworthy area of concern for additional emphasis appears to be in simulator fidelity.

B. FLIGHT SCENARIOS / HELICOPTER MODELS

The flight scenarios were produced in order to generate reasonable representations of operational head velocities. Because actual tracking encounters would necessarily be brief, and highly dependent upon maneuver dynamics, this is a difficult parameter to quantify. The scenarios developed for OATS did not involve aggressive flight as would be expected in an air to air engagement. The straight, curvilinear and hover scenarios were tame in comparison, yet they allowed significant azimuth rates to occur at minimum ranges. The experimental goals for OATS included measuring pilotage and tracking response characteristics to varying visual cues in addition to head velocity changes. Therefore, compromise in the flight scenario development is justified and fits the experimental model. Future investigations may choose to push this design further.

The method of flight route generation needs revision for future simulations of this sort. Waypoint navigation is suitable only for the purpose it was intended for (target motion) within the context of the math model used. Automatic flight route generation needs to be pre-recorded using a more complex math model that displays better handling qualities. The models used for manual flight (TMAN, CONTR2, SMART) were well suited to the tracking tasks presented. These models, on the other hand, were not suited for reproducing specific flight paths and were developed with helicopter model handling qualities in mind.

C. BASELINE TRACKING DATA

The generation of baseline (ideal tracker) data for the OATS scenarios was of considerable importance in planning scenarios, validating data collection efforts, and visualizing anticipated pilot tracking performance. In addition, the graphs produced for each scenario serve as a yardstick to measure actual pilot tracking performance deviation from the ideal. The availability of this data certainly merits further analysis.

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APPENDIX

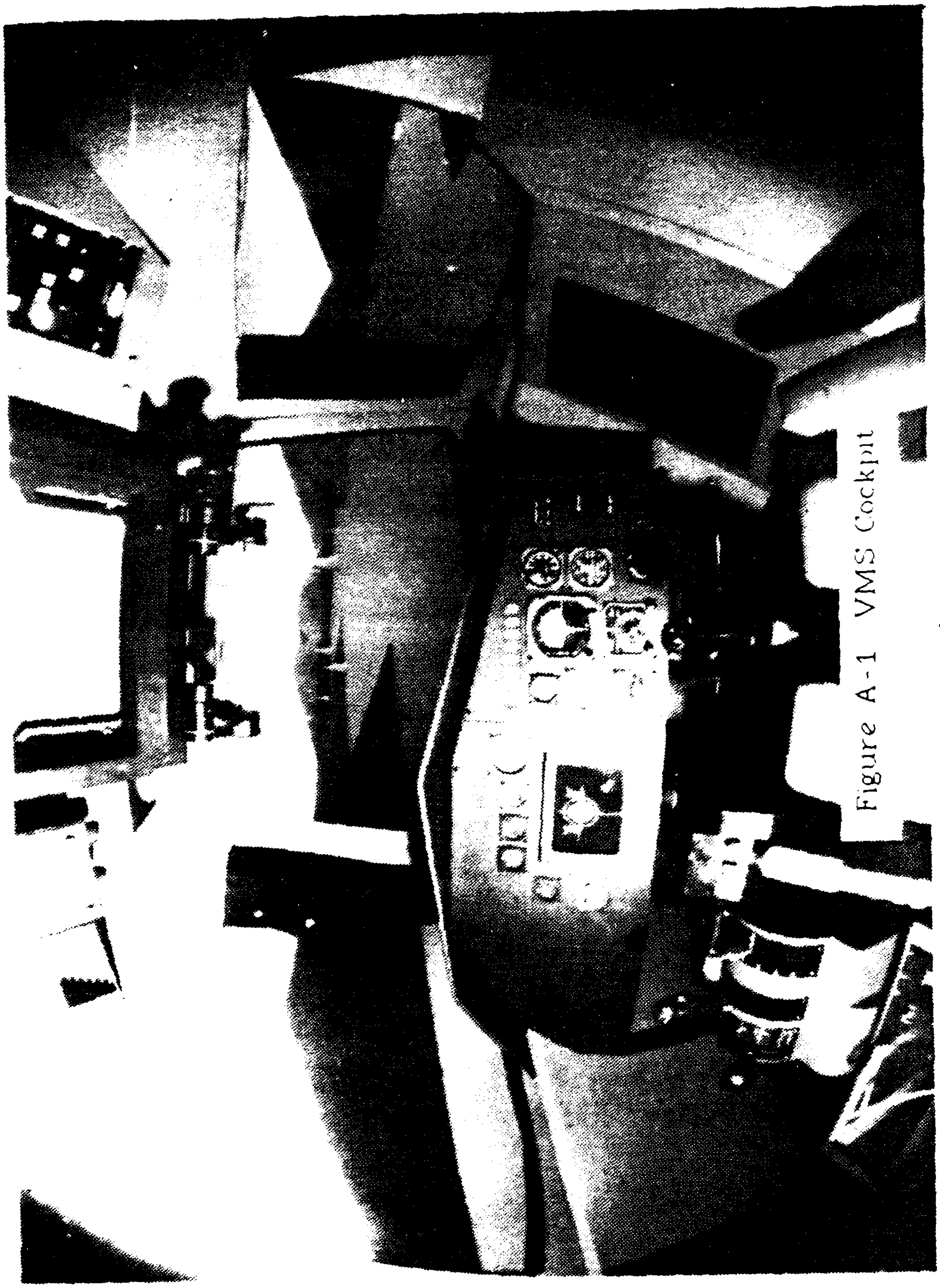

Figure A-1 VMS Cockpit

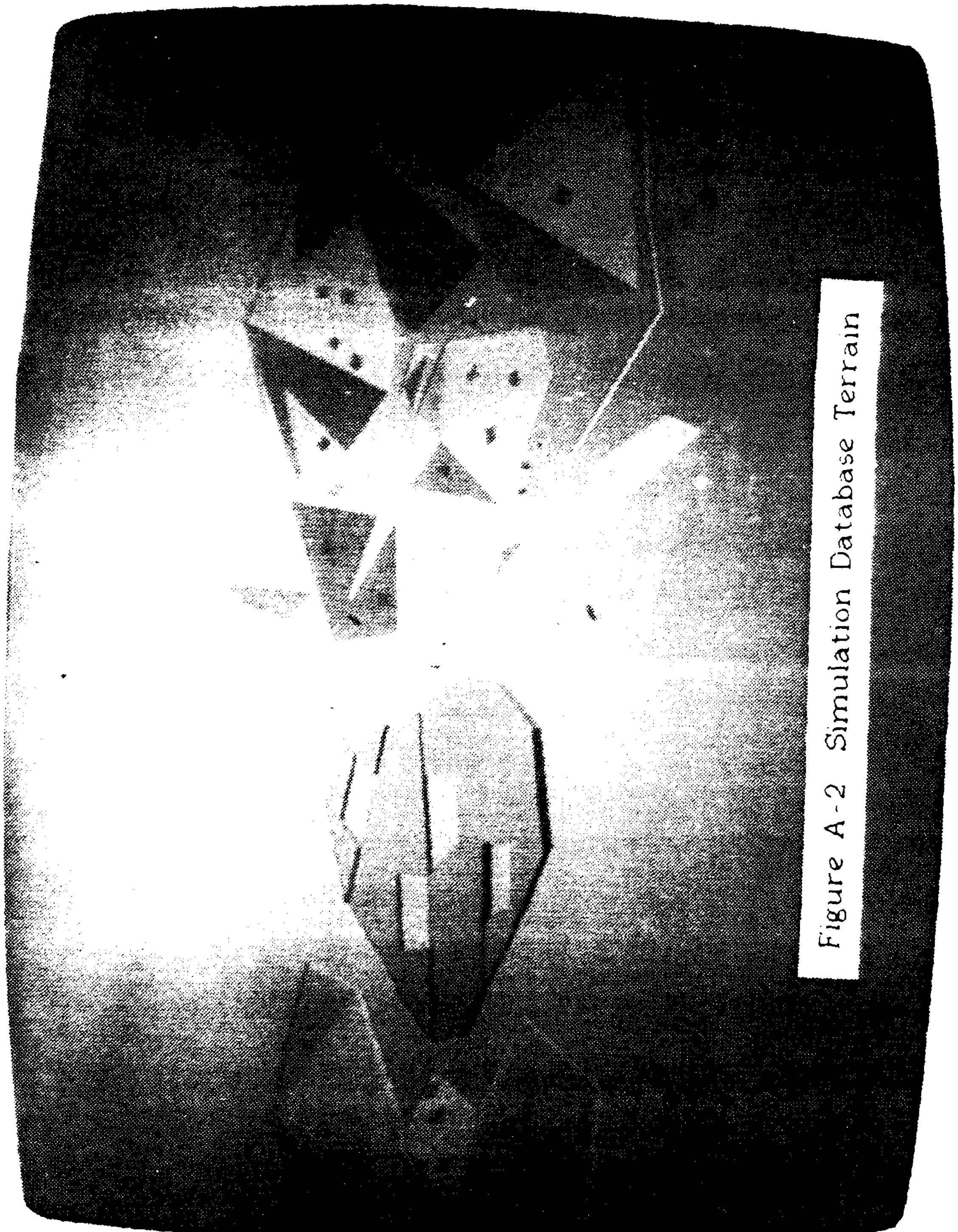

Figure A-2 Simulation Database Terrain

Figure A-3 Database Grid Orientations

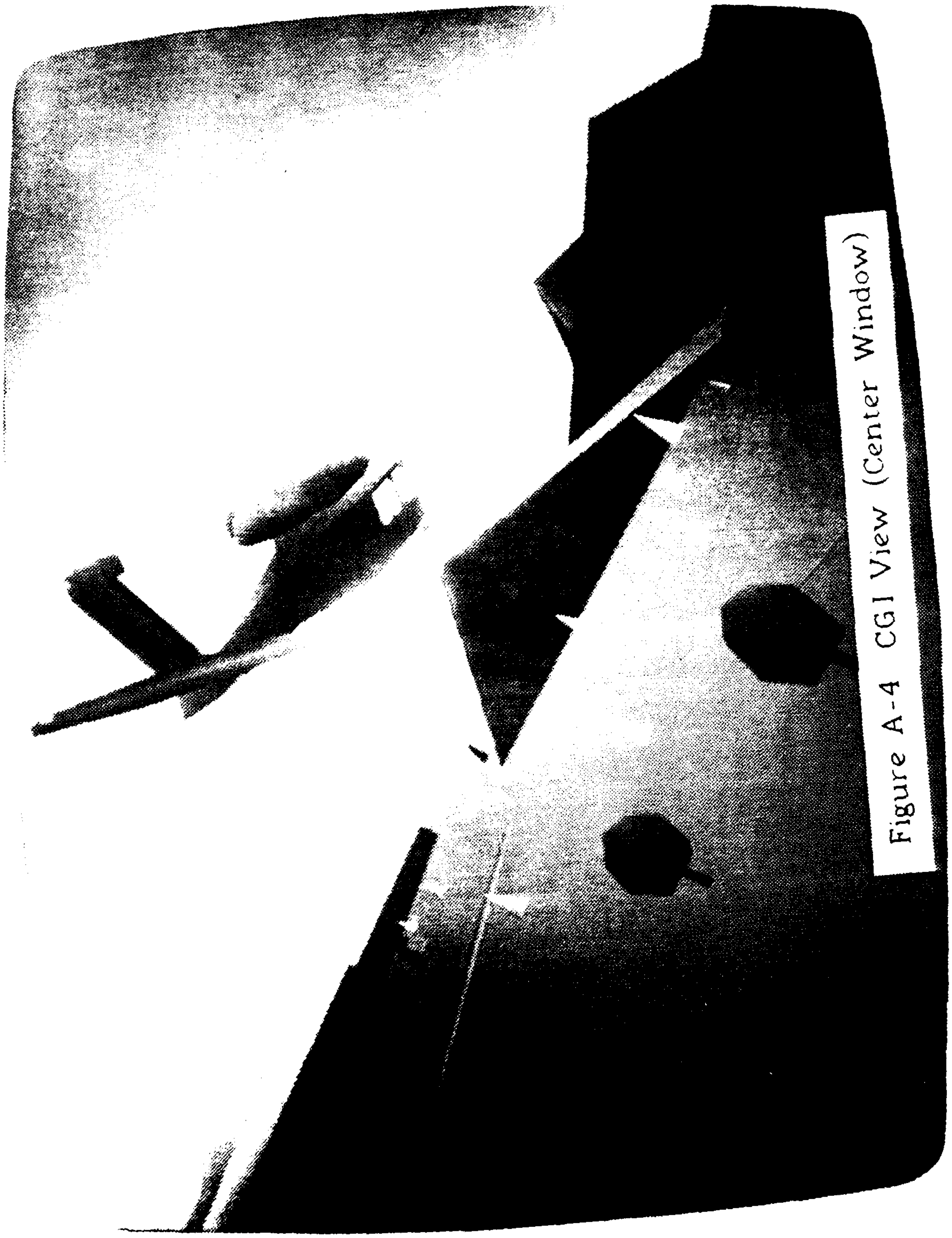

Figure A-4 CGI View (Center Window)

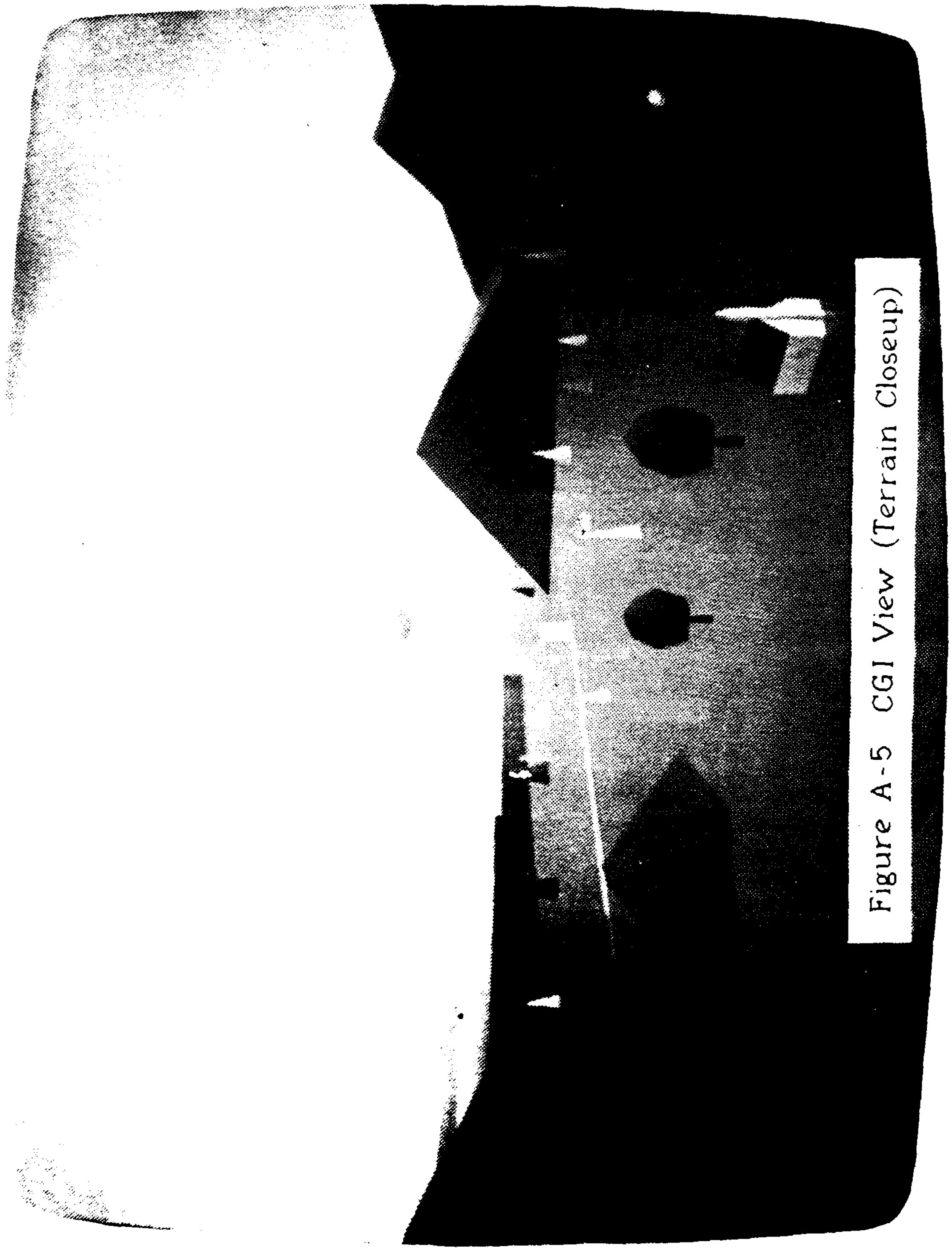

Figure A-5 CGI View (Terrain Closeup)

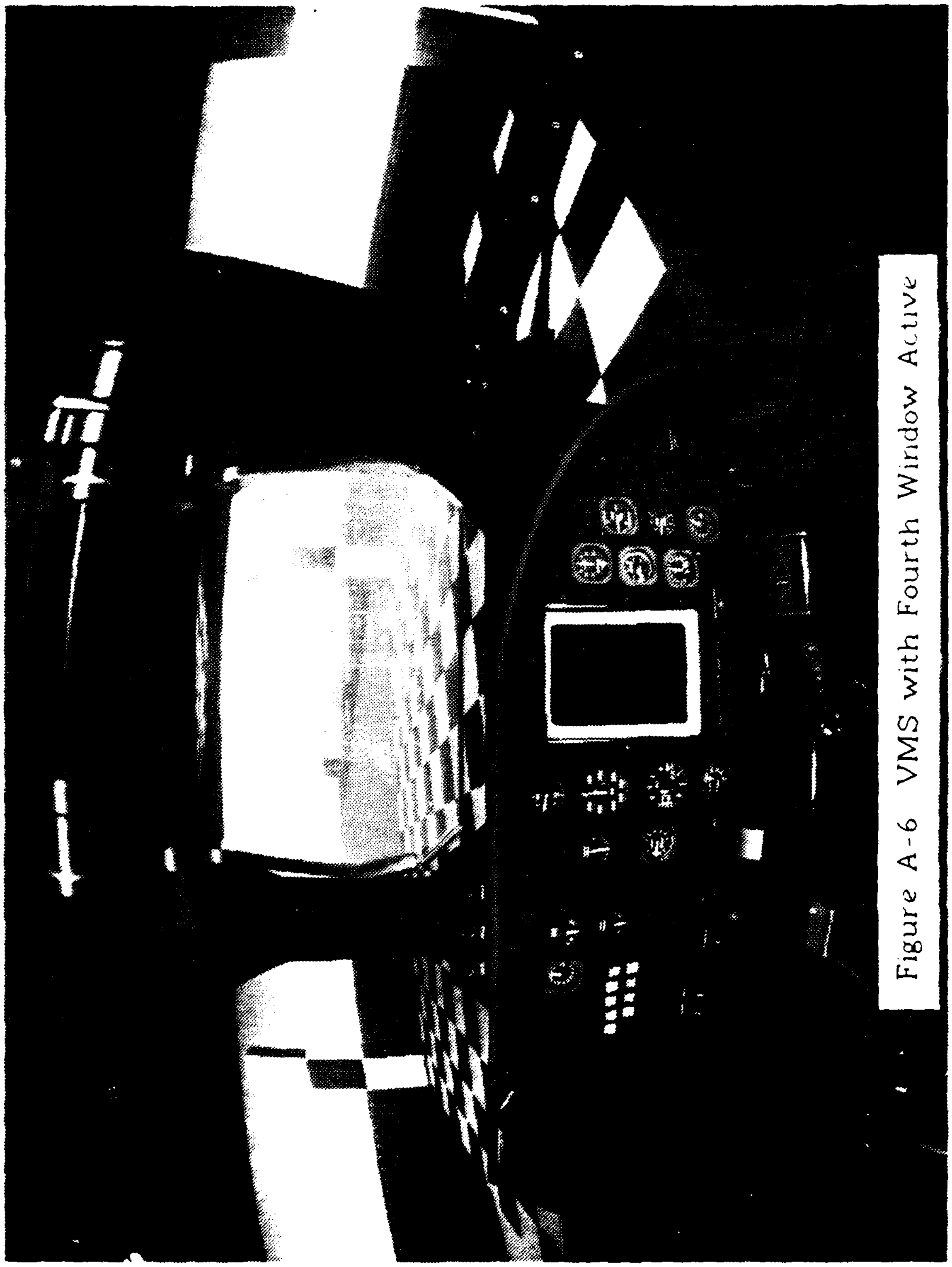

Figure A-6 VMS with Fourth Window Active

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